NTIS 273205

AD-273205

BRL

REPORT NO. 1154
NOVEMBER 1961

UNSTEADY SPHERICAL FLOW BEHIND A KNOWN SHOCK LINE

Ray C. Makino
Ralph E. Shear

Department of the Army Project No. 503-04-002
Ordnance Management Structure Code No. 5010.11.815

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

ASTIA AVAILABILITY NOTICE

Qualified requestors may obtain copies of this report from ASTIA.

BALLISTIC RESEARCH LABORATORIES

REPORT NO. 1154

NOVEMBER 1961

UNSTEADY SPHERICAL FLOW BEHIND A KNOWN SHOCK LINE

Ray C. Makino
Ralph E. Shear

Computing Laboratory
Terminal Ballistics Laboratory

Department of the Army Project No. 503-04-002
Ordnance Management Structure Code No. 5010.11.815

ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

REPORT NO. 1154

RCMakino/REShear/ic
Aberdeen Proving Ground, Md.
November 1961

UNSTEADY SPHERICAL FLOW BEHIND A KNOWN SHOCK LINE

ABSTRACT

The hydrodynamical equations of unsteady spherical flow are converted into characteristic form and solved numerically by a difference method. The "initial-value" curve is the shock line obtained by the least-square fit to some compiled shock-front data on spherical Pentolite, of such form as to approach Kirkwood-Brinkley's theoretical asymptotic shock-front decay curve. Results are tabulated on positive sound paths, mass particle paths, and lines of constant distance.

TABLE OF CONTENTS

SYMBOLS

Superscript:

i	represents iteration index
$*$	denotes dimensional quantity

Subscript:

o	denotes state of the undisturbed air
1,2,3,...	identify points in the t,m space

Roman

$a^* =$	radius of charge
$c^* =$	local sound velocity = $\sqrt{\left(\frac{\partial p^*(\rho^*, s^*)}{\partial \rho^*}\right)_{s^*}}$
$c =$	$\frac{c^*}{c^*_o}$
$e^* =$	specific internal energy
$e =$	$\frac{e^* - e^*_o}{c^{*2}_o}$
$E =$	$e + \frac{1}{2} u^2$
$h^* =$	specific enthalpy = $e^* + \frac{p^*}{\rho^*}$
$h =$	$\frac{h^* - h^*_o}{c^{*2}_o}$
$H =$	$h + \frac{1}{2} u^2$
$m =$	a function proportional to the mass between a particle path and the path of the boundary between air and explosion gas (see eq. II-7)
$p^* =$	total pressure
$p =$	$\frac{p^* - p_o}{p^*_o}$
$r^* =$	radial distance
$r =$	$\frac{r^*}{a^*}$
$R^* =$	gas constant

PRECEDING PAGE BLANK-NOT FILMED

s^* = specific entropy

$s = \frac{s^* - s^*_o}{R^*}$

S_{t_m} refers to the shock line in the t,m space

t^* = time

$t = \frac{c^*_o}{a^*} t^*$

T^* = absolute temperature

$T = \frac{T^*}{T^*_o}$

u^* = mass velocity of air

$u = \frac{u^*}{c^*_o}$

U^* = shock velocity

$U = \frac{U^*}{c^*_o}$

$W = \int_{t_{shock}}^{t} 4\,\pi r^2 \rho\, u\, d\, t\ ;$ constant m

Greek:

$\alpha_{t,m}$ refers to the forward-facing sound path in the t,m space

$\alpha_{t,r}$ refers to the forward-facing sound path in the t,r space

$\alpha_{p,u}$ refers to the forward-facing sound path in the p,u space

$\beta_{t,m}$ refers to the backward-facing sound path in the t,m space

$\beta_{t,r}$ refers to the backward-facing sound path in the t,r space

$\beta_{p,u}$ refers to the backward-facing sound path in the p,u space

$\gamma_{t,m}$	refers to the particle path in the t,m space
$\gamma_{t,r}$	refers to the particle path in the t,r space
$\gamma_{p,u}$	refers to the particle path in the p,u space
$\rho^* =$	density
$\rho =$	$1.4 \frac{\rho^*}{\rho_o^*}$
$\omega =$	$1.4 \frac{\rho^* c^*}{\rho_o^* c_o^*}$

I. INTRODUCTION

Extensive experimental data, obtained both by measurement of shock-front arrival times and by piezo-electric gage measurement of hydrostatic pressure change across the front, exist for the propagation of the blast wave from bare spherical charges exploded in air. These data are sufficient for the algebraic determination of all the remaining air flow parameters such as density, entropy, and particle velocity across the shock front. Parameters behind the front, however, cannot be measured as accurately nor be calculated as easily. The pressure-time curve recorded by the piezo-electric gage has scatter in the data in both the pressure p^* and the time t^* directions. But if these observed pressure-time records are assumed correct and known at each distance r^*, i.e., if the function

$$p^* = p^*(t^*, r^*)$$

is assumed known, then the particle velocity $u^* = u^*(t^*, r^*)$ and the entropy $s^* = s^*(t^*, r^*)$ can be calculated by integration of a set of ordinary differential equations (Ref. 1).

Here, we consider the numerical integration for the air flow parameters p^*, u^*, and s^*, given the shock line only, in the zone of determinacy of this line.

The system of partial differential equations describing this flow is of the hyperbolic type. At each point in the t^*, r^* space there exist three characteristics, two of which are path lines of sonic disturbances travelling outward and inward relative to the fluid particles, and the third of which is the path line of particles. This nature of the differential equations limits the domain of determinacy of the shock line; in particular, this domain cannot be extended into the zone of explosion gases without additional information about the zone.

The method of calculation consists of replacing the original system of flow equations by characteristics, which are written in finite difference form and solved numerically by step-by-step construction of the characteristic network. Computations are performed in the BRL electronic high-speed computer ORDVAC.

The shock-line chosen as the "initial curve" is an analytic expression fitted to some compiled experimental data on uncased spherical Pentolite charges fired in air at standard conditions away from reflecting obstacles. The smoothness of this curve necessarily destroys some information about discontinuities in the flow field.

The results are tabulated as functions of time along particle paths, positive sound paths, and constant radius lines. Some representative results are given graphically. These results may be not only of practical interest in the analysis of blast measuring apparatus and in the study of damage to structures, but may also be of theoretical interest in approximating blast-wave calculations.

II. EQUATIONS OF FLOW

The differential equations describing the continuous spherical flow of a non-conductive and non-viscous compressible fluid are, in Eulerian coordinates (Ref. 2),

Conservation of mass:

$$\text{(II-1)} \qquad \frac{\partial \rho^*}{\partial t^*} + u^* \frac{\partial \rho^*}{\partial r^*} + \rho^* \frac{\partial u^*}{\partial r^*} + \frac{2\rho^* u^*}{r^*} = 0;$$

Conservation of momentum:

$$\text{(II-2)} \qquad \frac{\partial u^*}{\partial t^*} + u^* \frac{\partial u^*}{\partial r^*} + \frac{1}{\rho^*} \frac{\partial p^*}{\partial r^*} = 0 ;$$

Adiabaticity:

$$\text{(II-3)} \qquad \frac{\partial s^*}{\partial t^*} + u^* \frac{\partial s^*}{\partial r^*} = 0 .$$

The independent coordinates are time t^* and distance r^*; the dependent are pressure p^*, mass velocity u^*, specific entropy s^*, density ρ^*, and sound velocity c^*. These equations are supplemented by the equations of state

$$\text{(II-4)} \qquad \begin{cases} c^* = c^*(p^*, s^*) , \\ \rho^* = \rho^*(p^*, s^*) , \end{cases}$$

which are tabulated for air in Ref. 3. By the total derivative of the equations above

$$d\rho^* = \frac{1}{c^{*2}} \, dp^* + \frac{\partial \rho^*(p^*, s^*)}{\partial s^*} \, ds^*$$

and by (II-3), we may put (II-1) into the form

$$\text{(II-5)} \qquad \frac{\partial p^*}{\partial t^*} + u^* \frac{\partial p^*}{\partial r^*} + c^{*2}\rho^* \frac{\partial u^*}{\partial r^*} + \frac{2c^{*2}\rho^* u^*}{r^*} = 0 .$$

In non-dimensional form equations (II-5), (II-2) and (II-3) become, respectively,

$$\text{(II-6)} \qquad \begin{cases} \dfrac{\partial p}{\partial t} + u \dfrac{\partial p}{\partial r} + \omega c \dfrac{\partial u}{\partial r} + \dfrac{2\omega c u}{r} = 0 . \\ \dfrac{\partial u}{\partial t} + u \dfrac{\partial u}{\partial r} + \dfrac{c}{\omega} \dfrac{\partial p}{\partial r} = 0 , \\ \dfrac{\partial s}{\partial t} + u \dfrac{\partial s}{\partial r} = 0 . \end{cases}$$

The Lagrangian form of these equations is obtained by replacing the independent variable r by a variable related to the mass bounded within the radial coordinate of each particle. We define a variable m such that

$$
\text{(II-7)} \quad \left\{ \begin{aligned} \frac{\partial m}{\partial r} &= \frac{\omega r^2}{c} \quad , \\ \frac{\partial m}{\partial t} &= -\frac{\omega r^2 u}{c} \; . \end{aligned} \right.
$$

The compatibility condition $\frac{\partial^2 m}{\partial r \partial t} = \frac{\partial^2 m}{\partial t \partial r}$ for continuous second derivatives reduces to the conservation of mass equation, and is automatically satisfied. m, so defined, is proportional to the fluid mass between two spherical shells of radii r_1 and r moving with the fluid. In particular, we let r_1 be the radius of the boundary between the explosion gas and air. The transformation (II-7) now converts the flow equations (II-6) into

$$
\text{(II-8)} \quad \left\{ \begin{aligned} &\frac{\partial p}{\partial t} + \omega^2 r^2 \frac{\partial u}{\partial m} + \frac{2\omega c u}{r} = 0 \, , \\ &\frac{\partial u}{\partial t} + r^2 \frac{\partial p}{\partial m} = 0 \, , \\ &\frac{\partial s}{\partial t} = 0 \, , \\ &\frac{\partial r}{\partial t} = u \end{aligned} \right.
$$

in the t, m space.

III. CHARACTERISTIC EQUATIONS

The system of partial differential equations (II-6) or (II-8) is of the hyperbolic type; i.e., three real characteristics exist in the t,r or t,m space along which discontinuities in derivatives can propagate (Ref. 2). We denote these characteristics by α, β and γ, with subscripts to specify the space. The characteristic equations then are:

$$\text{(III-1)} \quad \begin{cases} \alpha_{t,r}: & \dfrac{dr}{dt} = u + c \,, \\ \alpha_{t,m}: & \dfrac{dm}{dt} = \omega r^2 \,, \\ \alpha_{p,u}: & \dfrac{1}{\omega}\dfrac{dp}{dt} + \dfrac{du}{dt} = -\dfrac{2\,c\,u}{r} \,; \end{cases}$$

$$\text{(III-2)} \quad \begin{cases} \beta_{t,r}: & \dfrac{dr}{dt} = u - c \,, \\ \beta_{t,m}: & \dfrac{dm}{dt} = -\omega r^2 \,, \\ \beta_{p,u}: & \dfrac{1}{\omega}\dfrac{dp}{dt} - \dfrac{du}{dt} = -\dfrac{2\,c\,u}{r} \,; \end{cases}$$

$$\text{(III-3)} \quad \begin{cases} \gamma_{t,r}: & \dfrac{dr}{dt} = u \,, \\ \gamma_{t,m}: & \dfrac{dm}{dt} = 0 \,; \\ \gamma_{p,u}: & \dfrac{ds}{dt} = 0 \,. \end{cases}$$

Physically, the α and β characteristics correspond to the forward and backward facing sound paths respectively, and γ corresponds to the particle path. Solving this system of characteristic equations is equivalent to solving the original set of flow equations, (II-8) or (II-6).

IV. SHOCK-FRONT CONDITIONS AND INITIAL DATA

Across the discontinuous shock front travelling into stationary air with velocity U^*, the parameters of flow are related by the following Rankine-Hugoniot equations of conservation of mass, momentum and energy (Ref. 2).

Conservation of mass:

$$\rho^*(U^* - u^*) = \rho_o^* U^* \quad ;$$

Conservation of momentum:

$$\rho^*(U^* - u^*)^2 + p^* = \rho_o^* U^{*2} + p_o^* \; ;$$

Conservation of energy:

$$\frac{1}{2}(U^* - u^*)^2 + e^* + \frac{p^*}{\rho^*} = \frac{1}{2} U^{*2} + e_o^* + \frac{p_o^*}{\rho_o^*} \; .$$

These equations are derivable from (II-6) as weak solutions. We supplement the above equations by the equations of state

$$\rho^* = \rho^*(p^*, s^*) \; ,$$
$$e^* = e^*(p^*, s^*) \; ,$$
$$c^* = c^*(p^*, s^*) \; ,$$

where e^* is the specific internal energy. Shear and Day have tabulated these equations for air in Ref. 3. In the undisturbed state

p_o^*, u_o^*, s_o^*, the air is assumed to obey the ideal gas law $p_o^* = R^* \rho_o^* T_o^*$ with specific heat ratio 1.4.

In dimensionless form the equations above, together with the equations of the shock front path, may be written

$$
(\text{IV-1}) \quad \left\{ \begin{aligned}
&\frac{Dm}{Dt} = \frac{\partial m}{\partial t} + \frac{\partial m}{\partial r}\,\frac{Dr}{Dt} = 1.4\, r^2\, U \;, \\
&\frac{Dr}{Dt} = U \;, \\
&\frac{\omega}{c}\,(U - u) = 1.4\, U \;, \\
&\frac{\omega}{c}\,(U - u)^2 + p = 1.4 U^2 \;, \\
&\frac{1}{2}\,(U - u)^2 + e + \frac{(p+1)c}{\omega} = \frac{1}{2}\, U^2 + \frac{1}{1.4} \;, \\
&\omega = \omega\,(p,s) \;, \\
&c = c(p,s) \;, \\
&e = e(p,s) \;,
\end{aligned} \right.
$$

where D/Dt is differentiation along the shock line. The nine unknowns in the eight independent equations in (IV-1) above are m, r, p, u, s, U, ω, c, e. Thus, an experimental observation of any of these variables as a function of t or r determines the remaining variables as functions of t or r.

Extensive experimentation has been conducted on the propagation of shock waves from spherical Pentolite, because of the reproducibility of its explosion characteristics. Two methods of measurement have been commonly employed: in the first, shock arrival times between several points of observation are observed as functions of distance in the form $t = t(r)$, by either photographic observation of shock front path in the t,r plane or by piezo-electric gage observation of sudden pressure changes; in the second method, magnitudes of pressure jump across the shock are measured by means of piezo-electric gages with calibrated voltage output. Goodman (Ref. 4) has compiled these data and constructed the empirical fit

$$
(\text{IV-2}) \qquad p = 48.16 \left(\frac{r - 1}{r^3 \ln r} \right)^{\frac{1}{2}} \frac{(r - 1)^2 + 4198}{(r - 1)^2 + 247.0} \;,
$$

which approaches Kirkwood-Brinkley's asymptotic solution (Ref. 5) $\frac{p}{A} = \left(r^2 \ln \frac{r}{B}\right)^{-1/2}$ for $r \to \infty$ (A and B are constants). The fitting is based on an abundance of points for $1 < r < 100$, and on a relatively small

number for $100 < r < 200$. Kirkwood-Brinkley's asymptotic curve with parameters determined at $r = 150$ differs at most about 10 percent from this expression out to our maximum distance $r = 8200$. We somewhat arbitrarily consider $r = 150$ to be the demarkation point beyond which the shock line is equivalent to Kirkwood-Brinkley's asymptotic solution. Hence, the domain of determinacy of the experimental data lies between the positive characteristics $\alpha = 0$ and $\alpha = 91$ passing respectively thru the initial and $r = 150$ points on the shock line (Fig. 1).

From the empirical equation above and the shock conditions (IV-1) and also from the Hugoniot table of Ref. 3 are derived the complete shock-line values. We represent these values functionally by

$$\text{(IV-3)}\quad S: \begin{cases} m = m(t), \\ r = r(t), \\ p = p(t), \\ u = u(t), \\ s = s(t), \end{cases}$$

which we assume to be continuous and to possess continuous first derivatives. This set of functions will be regarded as the "initial-value" line for the numerical integration of the hydrodynamical equations of flow.

V. METHODS OF NUMERICAL INTEGRATION

Since, for shock velocity $U > 0$, the slopes $1.4\, r^2 U$ of $S_{t,m}$, ωr^2 of $\alpha_{t,m}$, $-\omega r^2$ of $\beta_{t,m}$ and 0 of $\gamma_{t,m}$, are respectively related by

$$\omega r^2 > 1.4\, r^2 U > 0 > -\omega r^2$$

(Ref. 2), no characteristics are tangent to the shock line; the domain of determinacy of the shock line in the t,m space is therefore the area bounded by the shock line $S_{t,m}$, the particle path $\gamma = 0$ through the initial point of $S_{t,m}$, and the forward-facing sound path $\alpha = 156$ through the terminus of $S_{t,m}$ (Fig. 1).

With the specified "initial data" we solve the flow equations by converting the equivalent characteristic equations into finite difference form. Though methods using differences higher than the first can be employed, machine limitations restricted the calculation here to first difference methods only in which the lattices are kept small. The coefficients of the differences are averaged, and improved after each cycle of the iterative process. The final results at each point are then accurate to the third order in lattice size, as we see later.

The difference scheme used is specifically as follows. In Figure 2, let $\widehat{12}$ and $\widehat{43}$ be segments of adjacent $\alpha_{t,m}$ lines given by the characteristic equations (III-1), $\widehat{14}$ and $\widehat{23}$ be segments of adjacent $\gamma_{t,m}$ lines given by the characteristic equations (III-3), and $\widehat{45}$ a segment of a $\beta_{t,m}$ line given by the characteristic equations (III-2).

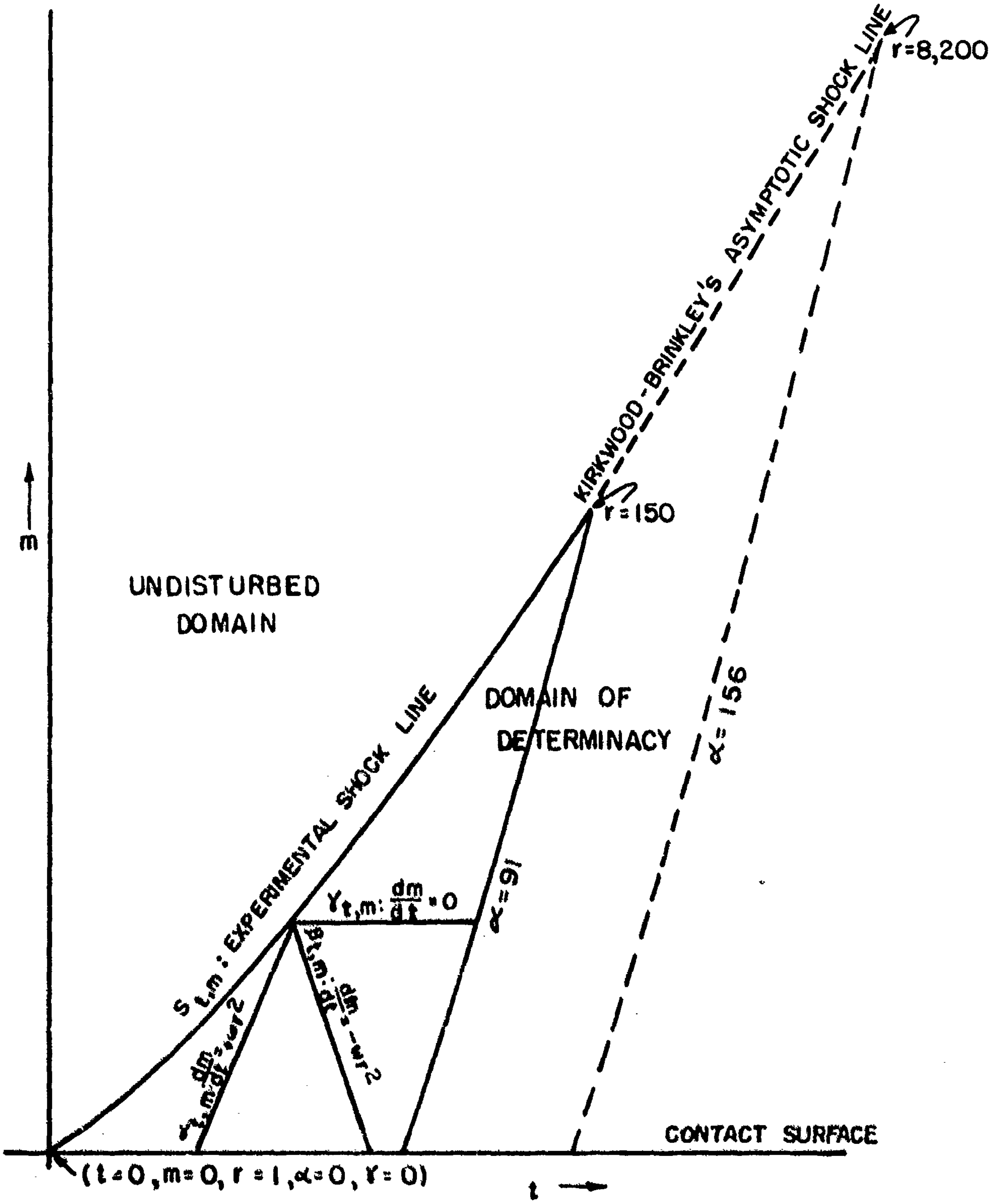


FIGURE I. CHARACTERISTICS AND DOMAIN OF DETERMINACY

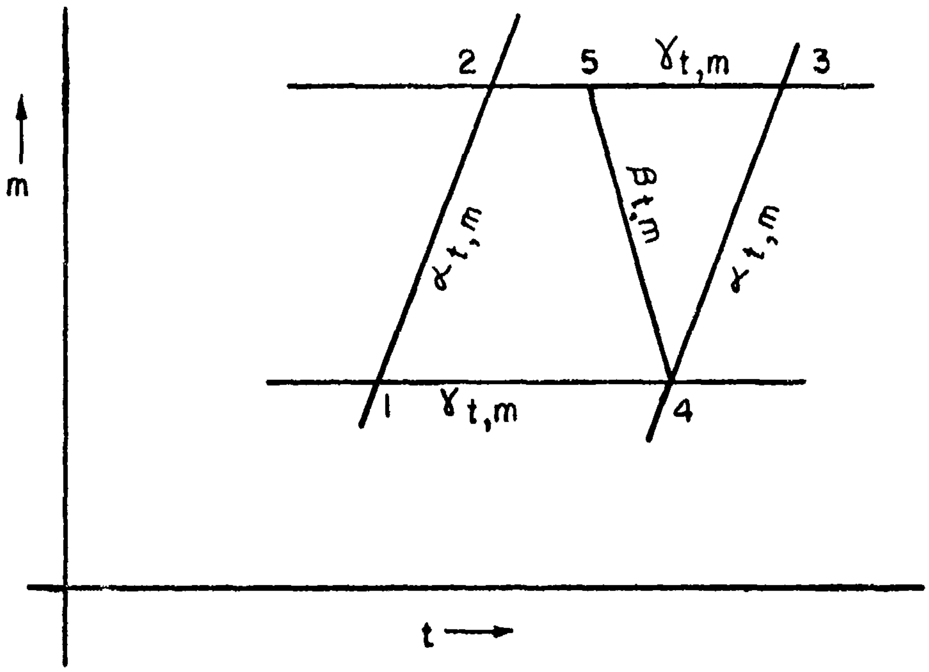


Figure 2. Construction of the Characteristic Lattice.

Of these five points let 1, 2 and 3 be completely known, let 4 be the point to be calculated, and let 5 be known to the (i - 1)'th iterative cycle. We denote the iterative cycle by superscript (i) and location of the points by numerical subscripts. The i'th values at point 4 are then calculated by means of the difference forms of the sets of characteristic equations (III-1), (III-2) and (III-3). The coordinates $t_4^{(i)}$, $m_4^{(i)}$ are calculated from the difference equations

$$
\text{(V-1)} \quad \left\{ \begin{array}{ll} \alpha_{t,m}: & \dfrac{m_4^{(i)} - m_3}{t_4^{(i)} - t_3} = \dfrac{(\omega r^2)_4{}^{(i-1)} + (\omega r^2)_3}{2} , \\ \gamma_{t,m}: & m_4^{(i)} = m_1 . \end{array} \right.
$$

The values of $t_5^{(i-1)}$ and t_2 are now compared. If $t_5^{(i-1)} - t_2 \geq 0$, then $t_5^{(i)}$, $m_5^{(i)}$ are calculated as the intersection of $\widehat{23}$ and $\widehat{45}$:

$$
\text{(V-2)} \quad \begin{cases} \beta_{t,m}: & \dfrac{m_5^{(i)} - m_4^{(i)}}{t_5^{(i)} - t_4^{(i)}} = - \dfrac{(\omega r^2)_5^{(i-1)} + (\omega r^2)_4^{(i-1)}}{2} , \\ \gamma_{t,m}: & m_5^{(i)} = m_2 . \end{cases}
$$

If $t_5^{(i-1)} - t_2 < 0$, then $t_5^{(i)}$, $m_5^{(i)}$ are calculated as the intersection of $\widehat{12}$ and $\widehat{45}$:

$$
\text{(V-3)} \quad \begin{cases} \beta_{t,m}: & \dfrac{m_5^{(i)} - m_4^{(i)}}{t_5^{(i)} - t_4^{(i)}} = - \dfrac{(\omega r^2)_5^{(i-1)} + (\omega r^2)_4^{(i-1)}}{2} , \\ \alpha_{t,m}: & m_5^{(i)} = m(t_5^{(i)}) , \end{cases}
$$

where $m_5^{(i)} = m(t_5^{(i)})$ is either an interpolation formula or the difference equation along $\widehat{12}$. That is, if point 5 is on $\widehat{23}$ in the $(i - 1)$'th iteration cycle, the $\gamma_{t,m}$ curve through point 2 is used to find the i'th value of point 5; but if the $(i - 1)$'th value of point 5 is on $\widehat{12}$, the $\alpha_{t,m}$ curve through point 2 is used. All other required quantities at point 5 are obtained either by the interpolation formulas

$$
\text{(V-4)} \quad \begin{cases} r_5^{(i)} = r(t_5^{(i)}) , \\ p_5^{(i)} = p(t_5^{(i)}) , \\ u_5^{(i)} = u(t_5^{(i)}) , \\ \omega_5^{(i)} = \omega(t_5^{(i)}) , \\ c_5^{(i)} = c(t_5^{(i)}) , \end{cases}
$$

along $\widehat{23}$ or $\widehat{12}$, or by the difference equations along these arcs, depending on the location of point 5. (Machine limitation required that we represent $\widehat{12}$ and $\widehat{23}$ by linear interpolation formulas in our computation.)

An alternative procedure for calculating point 5 is to use either the set of β and γ equations only or the set of β and α equations only, rather than to alternate between the two sets depending on the previous iterative value of t_5; but in this case the accuracy of the constructed $\beta_{t,m}$ curve through point 4 decreases with increasing distance of point 5 from the lattice $\widehat{1234}$. Another method for calculating point 5 is to use the β equations and the curve $\widehat{13}$ represented by interpolation formulas between points 1 and 3; but in this method machine round-off difficulties will be encountered in regions where the geometry of the lattice $\widehat{1234}$ is such that the curve $\widehat{13}$ is nearly tangent to either of the characteristics $\widehat{14}$ or $\widehat{34}$.

With point 5 known, p and u at point 4 can be calculated from

$$
(\text{V-5})\begin{cases}
\alpha_{p,u}: & \dfrac{\left(\frac{1}{\omega}\right)_4^{(i-1)} + \left(\frac{1}{\omega}\right)_3}{2}\,\dfrac{p_4^{(i)} - p_3}{t_4^{(i)} - t_3} + \dfrac{u_4^{(i)} - u_3}{t_4^{(i)} - t_3} = -\dfrac{\left(\frac{2cu}{r}\right)_4^{(i-1)} + \left(\frac{2cu}{r}\right)_3}{2}, \\[2ex]
\beta_{p,u}: & \dfrac{\left(\frac{1}{\omega}\right)_4^{(i-1)} + \left(\frac{1}{\omega}\right)_5^{(i)}}{2}\,\dfrac{p_4^{(i)} - p_5^{(i)}}{t_4^{(i)} - t_5^{(i)}} - \dfrac{u_4^{(i)} - u_5^{(i)}}{t_4^{(i)} - t_5^{(i)}} = -\dfrac{\left(\frac{2cu}{r}\right)_4^{(i-1)} + \left(\frac{2cu}{r}\right)_5^{(i)}}{2},
\end{cases}
$$

and r and s can be obtained from

$$
(\text{V-6})\begin{cases}
\gamma_{t,r}: & \dfrac{r_4^{(i)} - r_1}{t_4^{(i)} - t_1} = \dfrac{u_4^{(i)} + u_1}{2}, \\[2ex]
\gamma_{p,u}: & s_4^{(i)} = s_1 .
\end{cases}
$$

ω and c at point 4 are obtained from the equations of state

$$\text{(V-7)} \quad \begin{cases} \omega_4^{(i)} = \omega(p_4^{(i)}, \ s_4^{(i)}) \ , \\ c_4^{(i)} = c(p_4^{(i)}, \ s_4^{(i)}) \ . \end{cases}$$

Thus, the i 'th values of all the variables $t_4^{(i)}$, $m_4^{(i)}$, $r_4^{(i)}$, $p_4^{(i)}$, $u_4^{(i)}$, $\omega_4^{(i)}$ and $c_4^{(i)}$ are determined. The process is repeated until the (i + 1)'th and the i'th values differ insignificantly.

In the above procedure, when i = 1 the 0'th iterative values at point 4 required for averaging of coefficients of the difference equations can be obtained either by extrapolating along the computed $\alpha_{t,m}$ curve through point 3 down to $m_4 = m_1$ or by averaging the coefficients at points 1 and 3. For example, we can set, as is done in this report,

$$(\omega r^2)_4^{(0)} = (\omega r^2)_5^{(0)} = \frac{(\omega r^2)_1 + (\omega r^2)_3}{2} \ .$$

For the $t_5^{(0)}$ that we require in the comparison of $t_5^{(0)}$ with t_2 before point 5 is calculated, we can similarly use the average

$$t_5^{(0)} = \frac{t_1 + t_3}{2} \ .$$

A special case of the above procedure for calculating point 4 occurs in the neighborhood of the shock line. Here, the procedure is the same as at interior points, except that points 2 and 3 are considered coincident (Fig. 3), and interpolations (V-4) along $\widehat{12}$ are carried out along the shock line $S_{t,m}$ rather than along $\gamma_{t,m}$ or $\alpha_{t,m}$ thru 2.

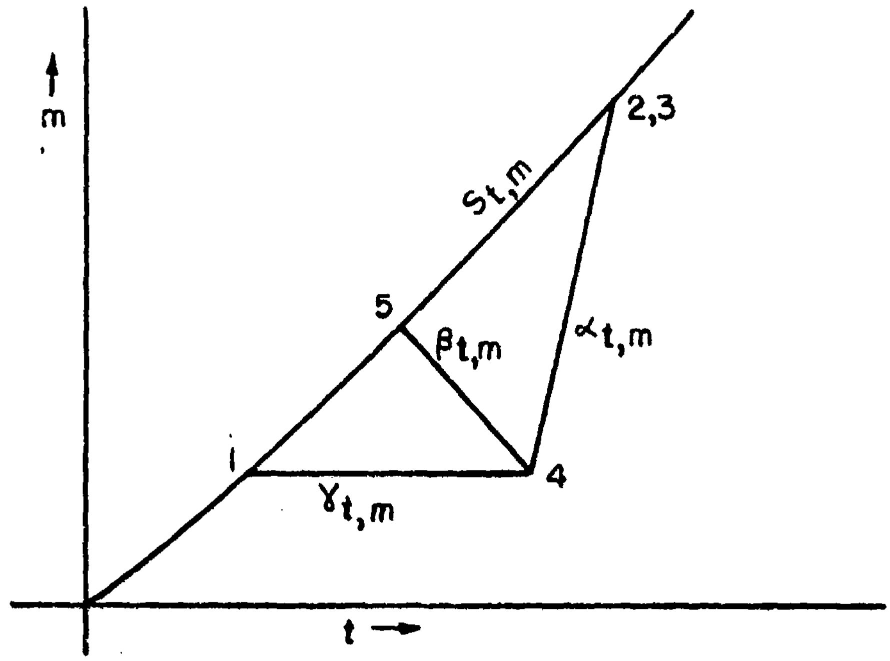


Figure 3. Characteristic Lattice Adjoining the Shock Line

The points integrated by the preceding scheme may be indexed by assigning successive values to the members of the α and γ characteristics, such that on the shock line these indices are equal. The characteristic network in the α , γ space would then be as given in Fig. 4. The known points on the shock line S are (1,1), (2,2), (3,3), etc., and the unknown points below S are calculated in the sequence (1,0), (2,1), (2,0), (3,2), (3,1), (3,0), etc.

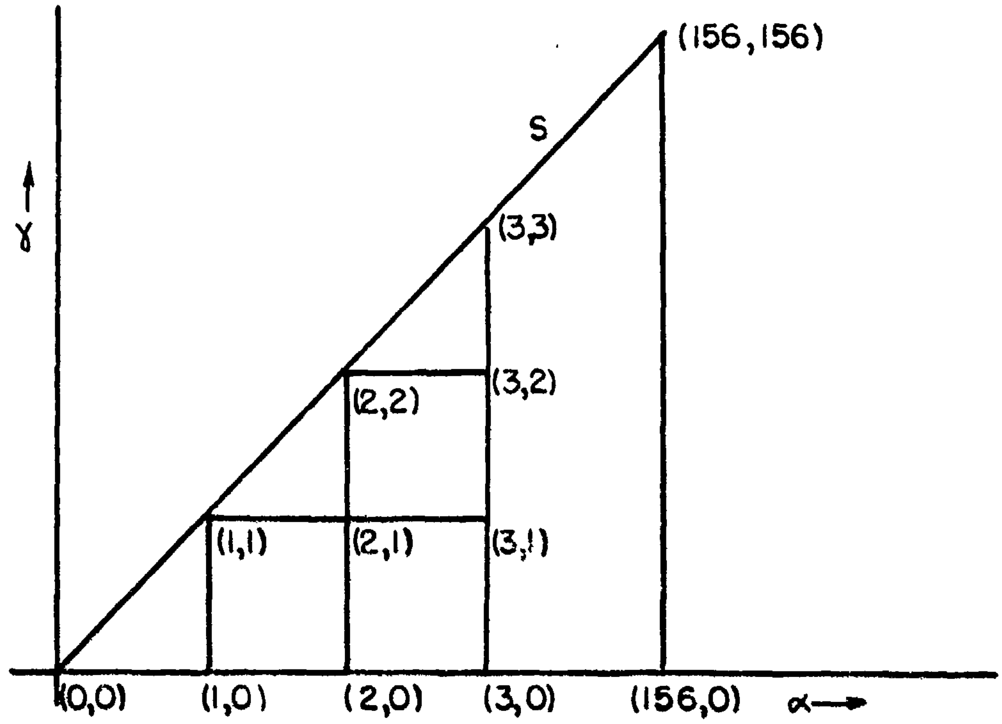


Figure 4. Lattice in α , γ Space

Once the lattice points along the shock line are chosen, the lattice network in the domain of integration becomes determined, unless the structure of the network is arbitrarily changed somewhere in the domain. Therefore, to minimize round-off errors, the shock-line lattice size in the t,m space is made variable. In the decaying shock considered here, the lattice interval Δt along the shock line is made an increasing function of t.

The integration process described uses $\gamma_{t,m}$ and $\alpha_{t,m}$ equations to determine the characteristic network points in the t,m space; i.e., the lattices are rectangular in the α, γ space in regions away from the shock line. Thus, integration results, including values on the boundaries of the domain of determinacy, become tabulated on α and γ characteristics, and values on β characteristics must be obtained by interpolation of the results. If, however, results along other combinations of characteristics are preferred, the process can be modified. We can, for example, construct the characteristic network in the α, β space. In Fig. 2, if points 5 and 3 are known, difference forms of the $\alpha_{t,m}$ and $\beta_{t,m}$ characteristic equations in (III-4) and (III-5) respectively can be used to determine the quantities t_4, m_4. In the special case

that values along γ are not of interest, this method has the advantage that only s_4 need be interpolated as a function of m_4, whereas all interpolations (V-4) are required in the previous method; however, it has the disadvantage of requiring a special procedure at the boundary $\gamma = 0$ separating air from the explosion gas.

A still another method is to choose the integration points arbitrarily along constant t lines, say $t = t_1 + \Delta t$ (Figure 5), and to employ the intersection points 1, 2, and 3 of the $\alpha_{t,m}$, $\beta_{t,m}$, $\gamma_{t,m}$ characteristics respectively with the known line $t = t_1$ to calculate quantities at the integration point 4. This procedure is permissible because t = constant lines are nowhere tangent to any characteristic in any continuous and finite domains. However, several disadvantages arise. Firstly, the lack of automatic adjustment of network size according to gradients, as in the methods that construct the characteristic network, necessitates the determination of Δm along each constant t line according to the results obtained for previous times, in order to control errors. Secondly, interpolations must be performed at all three points 1, 2 and 3, whereas previous methods required this operation at one point only. Thirdly, a special procedure is required to determine the $\gamma = 0$ boundary passing through the initial point of the shock line. Finally, values along characteristics that may be desired for theoretical studies must all be subsequently interpolated for.

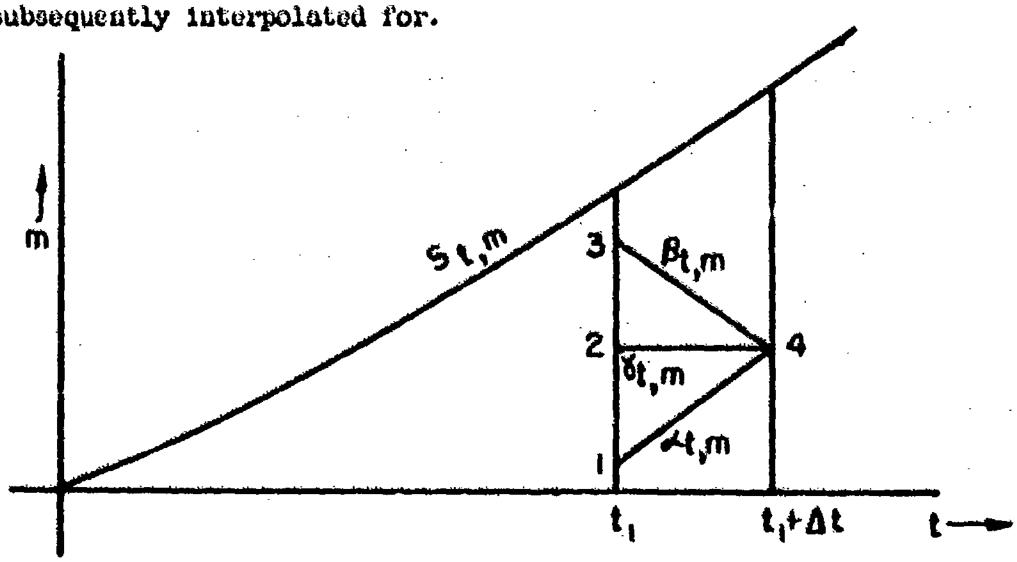


Figure 5. Integration Along Constant t Lines.

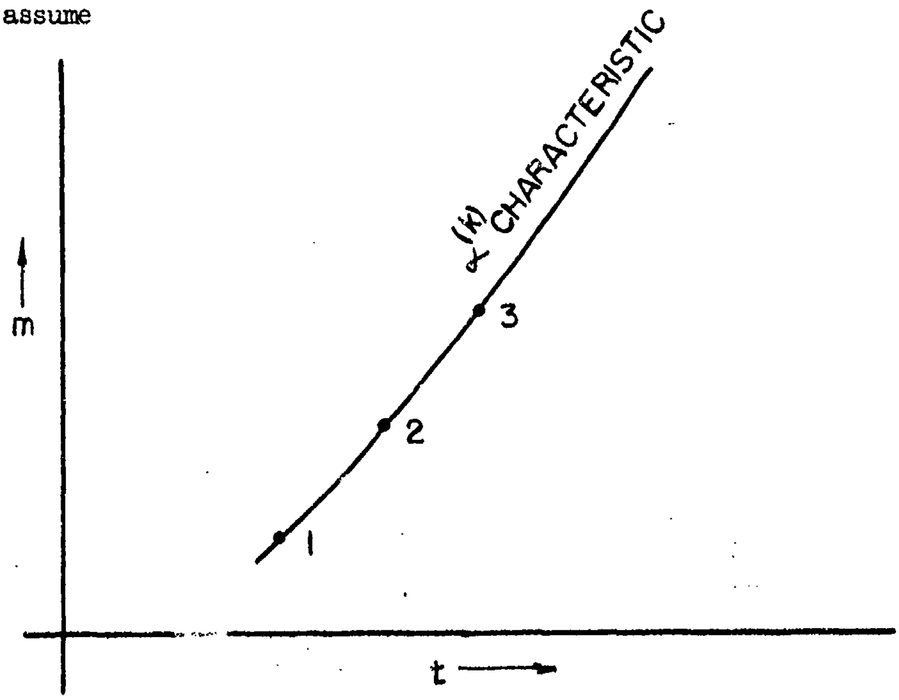
The existence theorem shows that integration methods based on differencing the original system of flow equations (II-8) rather than differencing the characteristic system require that the unknown point be within the domain of determinacy of the known points used in the difference scheme (Ref. 5). Since this condition must be examined at every integration point, complete use of the characteristic method is simpler and probably more accurate where the integration zone is fairly smooth, such as occurs in this report.

VI. INTEGRATION ERRORS

The sets of characteristic equations (III-1), (III-2) and (III-3) are in the form

$$\text{(VI-1)} \qquad \sum_{j=1}^{6} f^{(jk\ell)} \left(\phi^{(1)},\ldots,\phi^{(6)}\right) \frac{\partial \phi^{(j)}}{\partial \alpha^{(k)}} = g^{(k\ell)}\left(\phi^{(1)},\ldots,\phi^{(6)}\right),$$

where $\phi^{(j)}$ represents one of the set of six variables (t, m, r, p, u, s), $\alpha^{(k)}$ represents one of the three characteristic variables (α, β, γ), and superscript ℓ refers to one of the spaces (t,r), (t,m) or (p,u). If we assume



$f^{(jk\ell)}$, $g^{(k\ell)}$ and $\phi^{(j)}$ to be expandable in convergent series in the arc $\widehat{13}$ along the $\alpha^{(k)}$ characteristic, we have

$$f_3^{(jk\ell)} = f_2^{(jk\ell)} + \frac{1}{1!}\left(\frac{\partial f^{(jk\ell)}}{\partial\alpha^{(k)}}\right)_2(\Delta\alpha^{(k)}) + \frac{1}{2!}\left(\frac{\partial^2 f^{(jk\ell)}}{\partial\alpha^{(k)2}}\right)_2(\Delta\alpha^{(k)})^2 + \ldots,$$

$$f_1^{(jk\ell)} = f_2^{(jk\ell)} - \frac{1}{1!}\left(\frac{\partial f^{(jk\ell)}}{\partial\alpha^{(k)}}\right)_2(\Delta\alpha^{(k)}) + \frac{1}{2!}\left(\frac{\partial^2 f^{(jk\ell)}}{\partial\alpha^{(k)2}}\right)_2(\Delta\alpha^{(k)})^2 + \ldots,$$

$$g_3^{(k\ell)} = g_2^{(k\ell)} + \frac{1}{1!}\left(\frac{\partial g^{(k\ell)}}{\partial\alpha^{(k)}}\right)_2(\Delta\alpha^{(k)}) + \frac{1}{2!}\left(\frac{\partial^2 g^{(k\ell)}}{\partial\alpha^{(k)2}}\right)_2(\Delta\alpha^{(k)})^2 \quad ,$$

$$g_1^{(k\ell)} = g_2^{(k\ell)} - \frac{1}{1!}\left(\frac{\partial g^{(k\ell)}}{\partial\alpha^{(k)}}\right)_2(\Delta\alpha^{(k)}) + \frac{1}{2!}\left(\frac{\partial^2 g^{(k\ell)}}{\partial\alpha^{(k)2}}\right)_2(\Delta\alpha^{(k)})^2 \quad ,$$

$$\phi_3^{(j)} = \phi_2^{(j)} + \frac{1}{1!}\left(\frac{\partial\phi^{(j)}}{\partial\alpha^{(k)}}\right)_2(\Delta\alpha^{(k)}) + \frac{1}{2!}\left(\frac{\partial^2\phi^{(j)}}{\partial\alpha^{(k)2}}\right)_2(\Delta\alpha^{(k)})^2 \quad ,$$

$$\phi_1^{(j)} = \phi_2^{(j)} - \frac{1}{1!}\left(\frac{\partial\phi^{(j)}}{\partial\alpha^{(k)}}\right)_2(\Delta\alpha^{(k)}) + \frac{1}{2!}\left(\frac{\partial^2\phi^{(j)}}{\partial\alpha^{(k)2}}\right)_2(\Delta\alpha^{(k)})^2 \quad ,$$

from which we obtain by addition and subtraction

$$\frac{f_3^{(jk\ell)} + f_1^{(jk\ell)}}{2} = f_2^{(jk\ell)} + \frac{1}{2!}\left(\frac{\partial^2 f^{(jk\ell)}}{\partial\alpha^{(k)2}}\right)_2(\Delta\alpha^{(k)})^2 + \ldots \quad ,$$

$$\frac{g_3^{(k\ell)} + g_1^{(k\ell)}}{2} = g_2^{(k\ell)} + \frac{1}{2!}\left(\frac{\partial^2 g^{(k\ell)}}{\partial\alpha^{(k)2}}\right)_2(\Delta\alpha^{(k)})^2 + \ldots \quad ,$$

$$\frac{\phi_3^{(j)} - \phi_1^{(j)}}{2} = \frac{1}{1!}\left(\frac{\partial\phi^{(j)}}{\partial\alpha^{(k)}}\right)_2(\Delta\alpha^{(k)}) + \frac{1}{3!}\left(\frac{\partial^3\phi^{(j)}}{\partial\alpha^{(k)3}}\right)_2(\Delta\alpha^{(k)})^3 + \ldots.$$

Solving these equations for $f_2^{(jk\ell)}$, $g_2^{(k\ell)}$ and $\left(\frac{\partial\phi^{(j)}}{\partial\alpha^{(k)}}\right)_2$

and substituting into (VI-1), we obtain

$$\text{(VI-2)} \quad \sum_{j=1}^{6} \left[\frac{f_3^{(jk\ell)} + f_1^{(jk\ell)}}{2} (\phi_3^{(j)} \quad \phi_1^{(j)}) \right] = \frac{g_3^{(k\ell)} + g_1^{(k\ell)}}{2} (\Delta\alpha^{(k)}) + 0(\Delta\alpha^{(k)})^3$$

This result indicates that for lattices sufficiently small the method of first-order differencing with average coefficients applied to the set of characteristic equations introduces a truncation error of third order in lattice size. While we can further reduce this error by integrating with several lattices and extrapolating the results to zero lattice (Ref. 6), the experimental accuracy of the shock line does not make the process worthwhile.

The relative round-off error is kept small by increasing the time step Δt along the shock line in accordance with the diminishing gradients of the variables.

The numerical study of error propagation and growth in scattered limited regions of the domain of integration by introduction of small changes in the variables, indicates that relative errors remain approximately of constant order.

VII. DISCUSSION OF RESULTS

The comparison between Brode's calculation on TNT (Ref. 7) based on the method of artificial viscosity and our results on Pentolite calculated by the method of characteristics, must be semi-qualitative, since the explosives and the nature of the initial and boundary values differ, and since Brode's scaling factors for time and distance depend on uncertain explosion energies ϵ^*. Brode's dimensionless time and distance are defined by

$$\tau = \frac{c_o^*}{\left(\frac{\epsilon^*}{p_o^*}\right)^{1/3}} t^* , \quad \lambda = \frac{1}{\left(\frac{\epsilon^*}{p_o^*}\right)^{1/3}} r^*$$

If $\lambda = 0.0156$ is the charge surface $r = 1$, as Fig. 16 in Brode's report seems to indicate, we can relate τ, λ to t, r by

$$t = \frac{1}{0.0156} \tau , \quad r = \frac{1}{0.0156} \lambda$$

Brode's curves transformed to t,r space are compared with our assumed shock line and computed data in Fig. 6. (Because of some inconsistencies between Brode's curves in Ref. 7, we have used only Fig. 16-21 in this reference, supplemented by some of his unpublished data on isobaric lines that he has kindly furnished us.)

As Fig. 6 indicates, the calculated results influenced by the asymptotic segment of the shock line are questionable. While the error may be due to fitting the asymptotic curve to inaccurate shock line data near the limit of observation, more probably the asymptotic formula itself requires modification in the direction of faster shock decay, so that pressure at any fixed distance as a function of time decays faster in accord with observation, and the expanding contact surface reverses its direction of motion, as it eventually must.

Typical graphs are drawn for the various variables along lines of constant α, γ, and r.

The tables give the shock line used as initial values, and the results along lines of constant α, γ, and r in the domain influenced by the experimental shock line only.

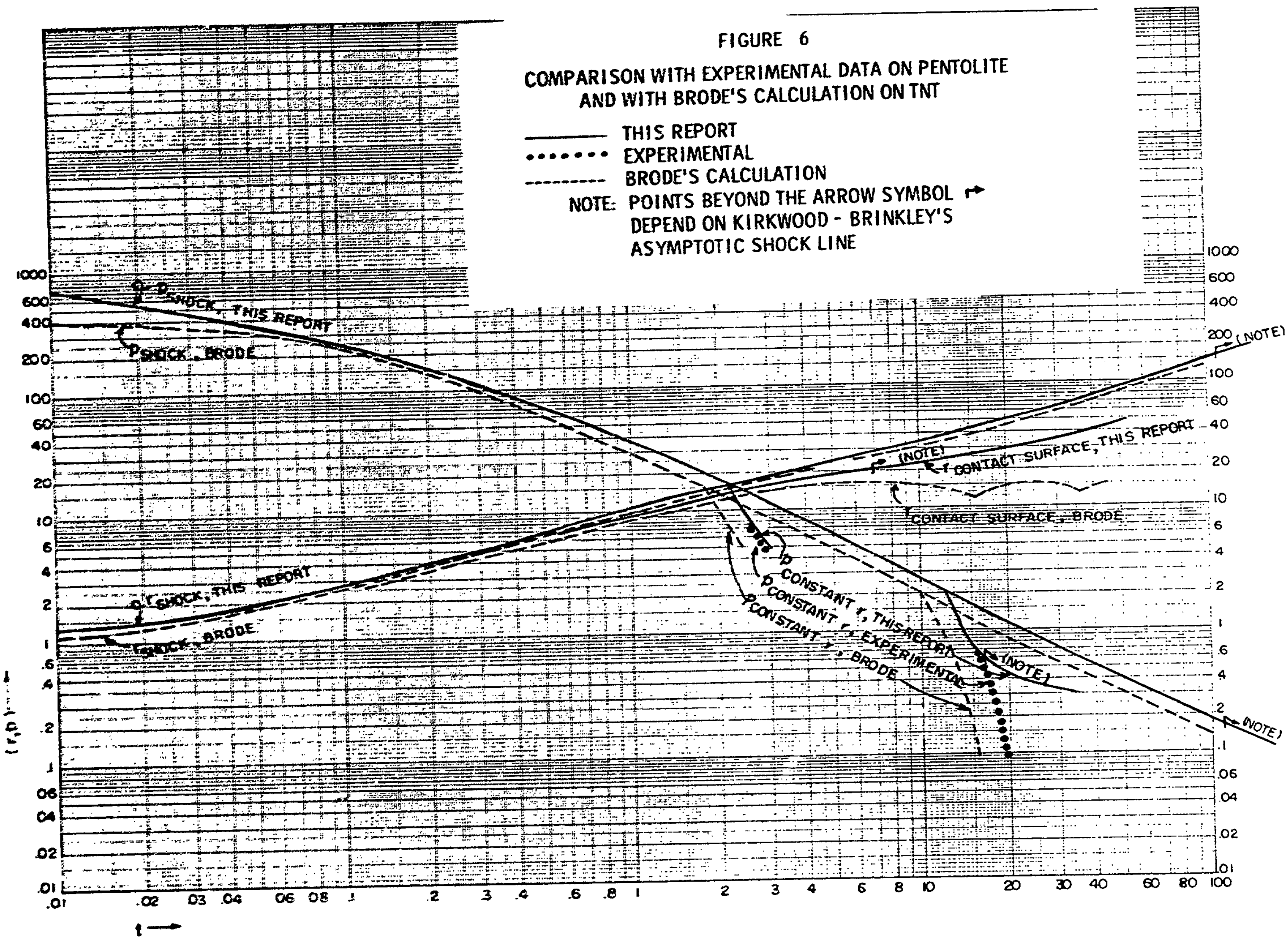


FIGURE 6
COMPARISON WITH EXPERIMENTAL DATA ON PENTOLITE AND WITH BRODE'S CALCULATION ON TNT
THIS REPORT
EXPERIMENTAL
BRODE'S CALCULATION
NOTE: POINTS BEYOND THE ARROW SYMBOL DEPEND ON KIRKWOOD - BRINKLEY'S ASYMPTOTIC SHOCK LINE
p SHOCK, THIS REPORT
p SHOCK, BRODE
r SHOCK, THIS REPORT
r SHOCK, BRODE
r CONTACT SURFACE, THIS REPORT
r CONTACT SURFACE, BRODE
p CONSTANT r, THIS REPORT
p CONSTANT r, EXPERIMENTAL
p CONSTANT r, BRODE
(NOTE)
(r, p)
t

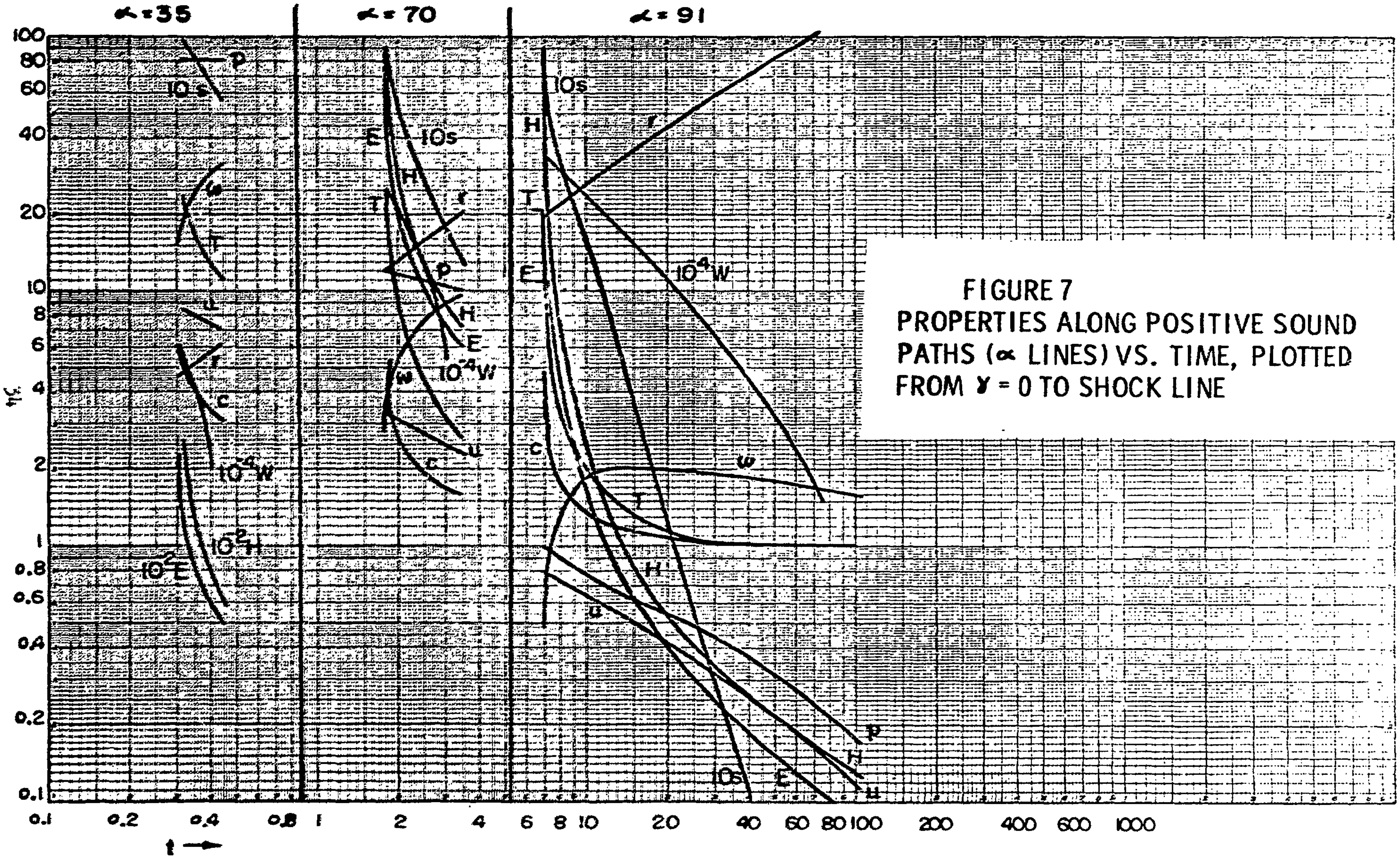


FIGURE 7
PROPERTIES ALONG POSITIVE SOUND PATHS (α LINES) VS. TIME, PLOTTED FROM γ = 0 TO SHOCK LINE

FIGURE 8. PROPERTIES ALONG POSITIVE SOUND PATH $\alpha = 156$ (IN ASYMPTOTIC DOMAIN) VS. TIME, PLOTTED FROM $\gamma = 0$ TO SHOCK LINE.

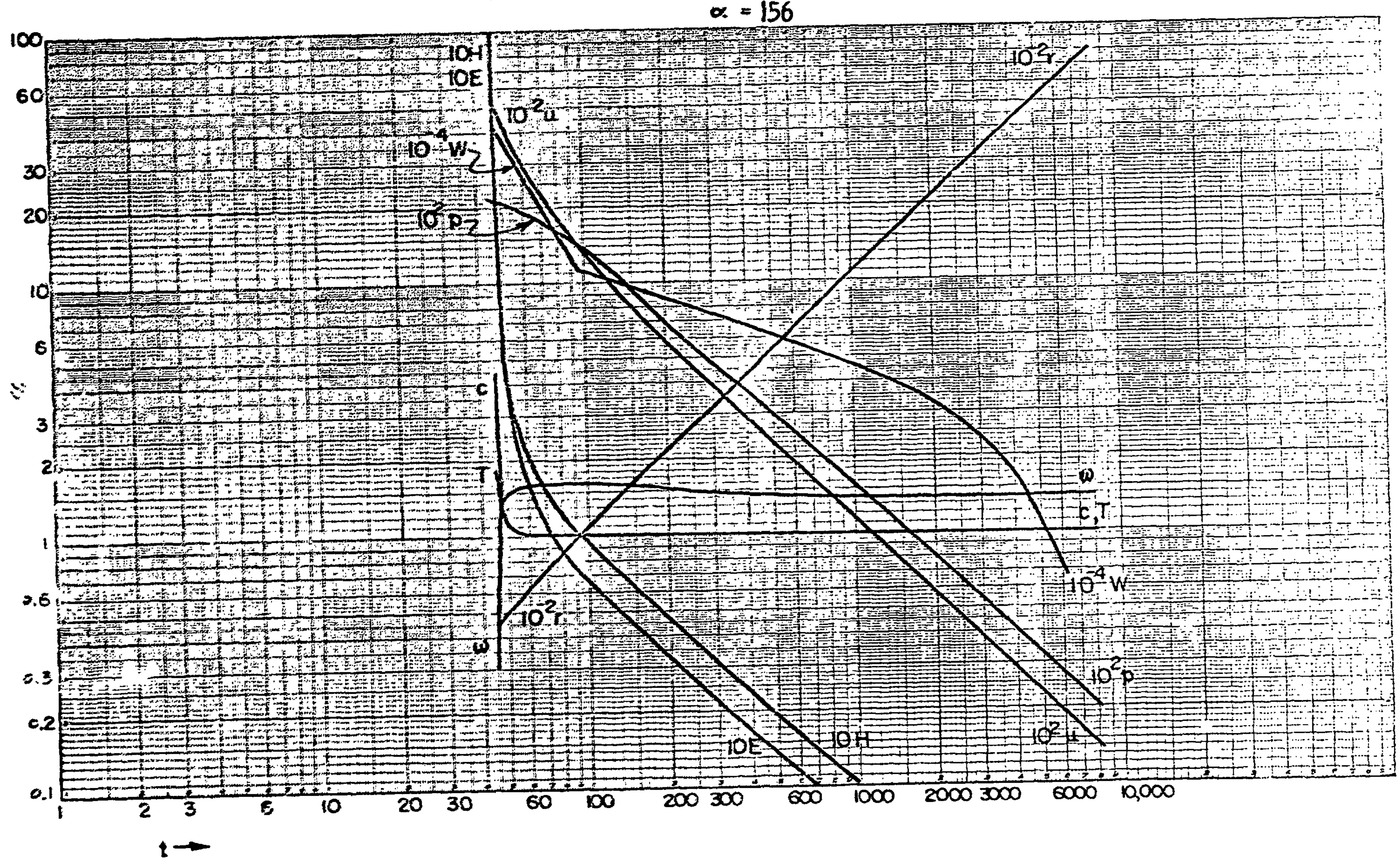
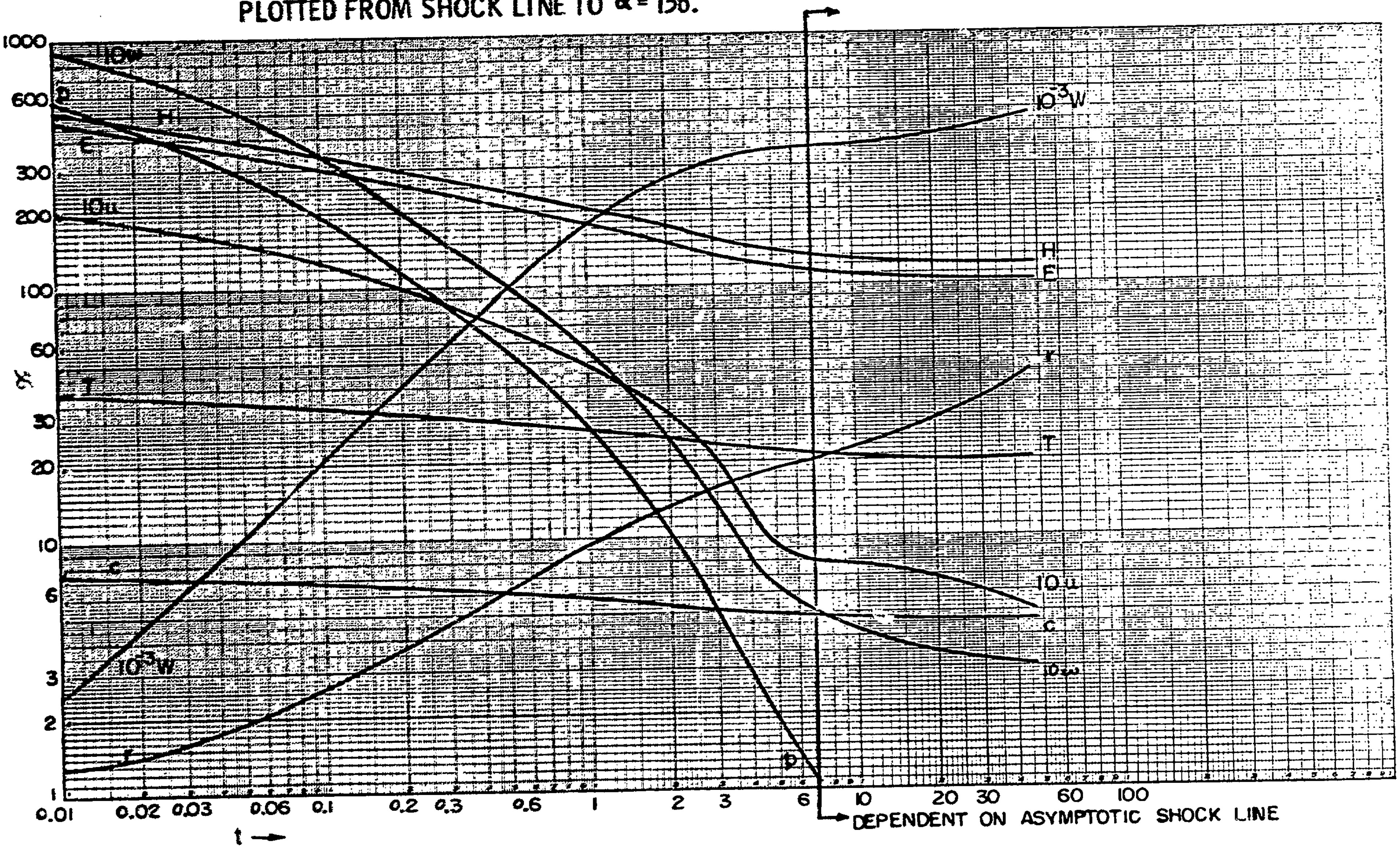


FIGURE 9. PROPERTIES ALONG PARTICLE PATH $\gamma = 0$, $s = 18.02$ (CONTACT SURFACE) VS. TIME, PLOTTED FROM SHOCK LINE TO $\alpha = 156$.



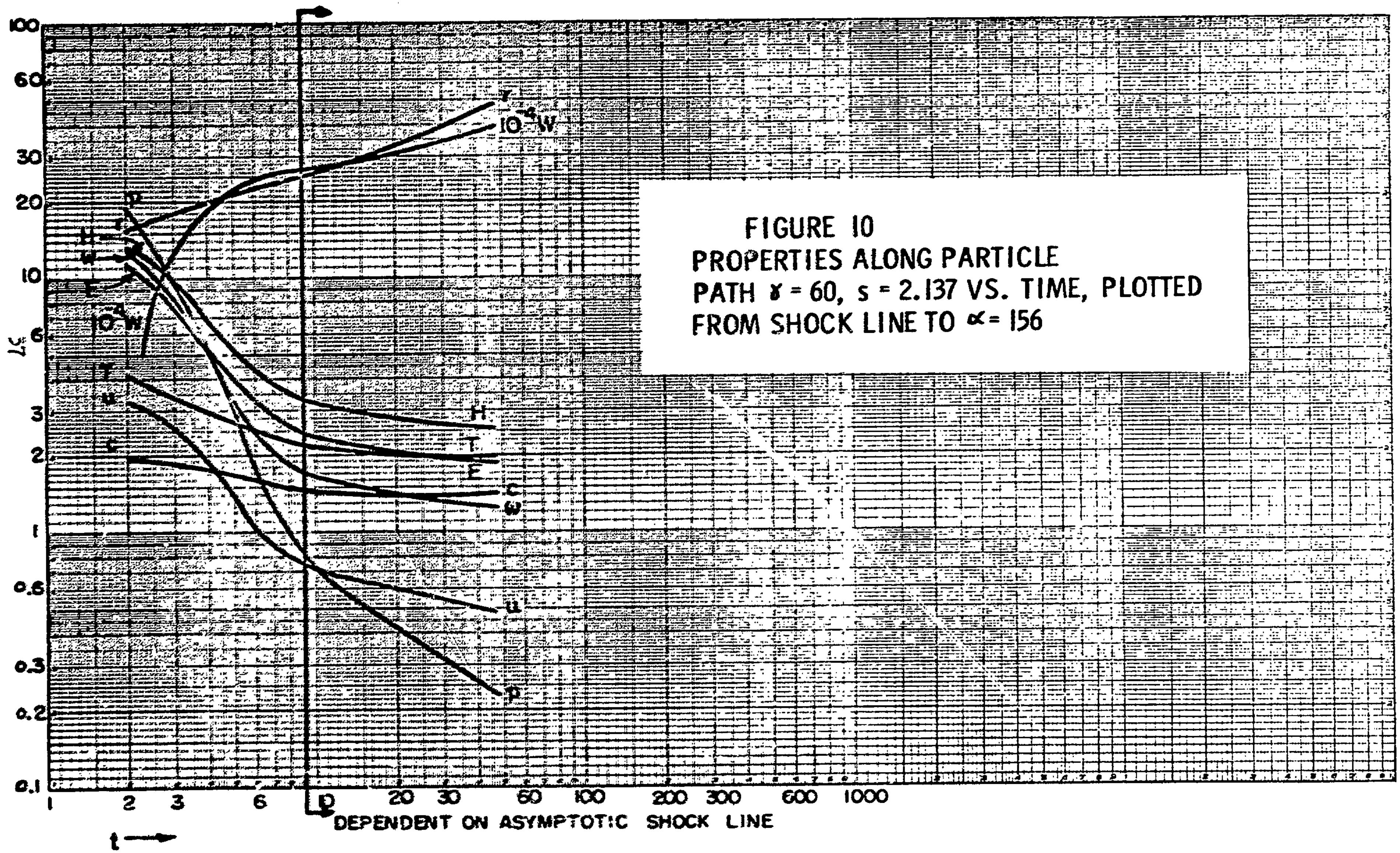


FIGURE 10
PROPERTIES ALONG PARTICLE PATH $\gamma = 60$, $s = 2.137$ VS. TIME, PLOTTED FROM SHOCK LINE TO $\alpha = 156$

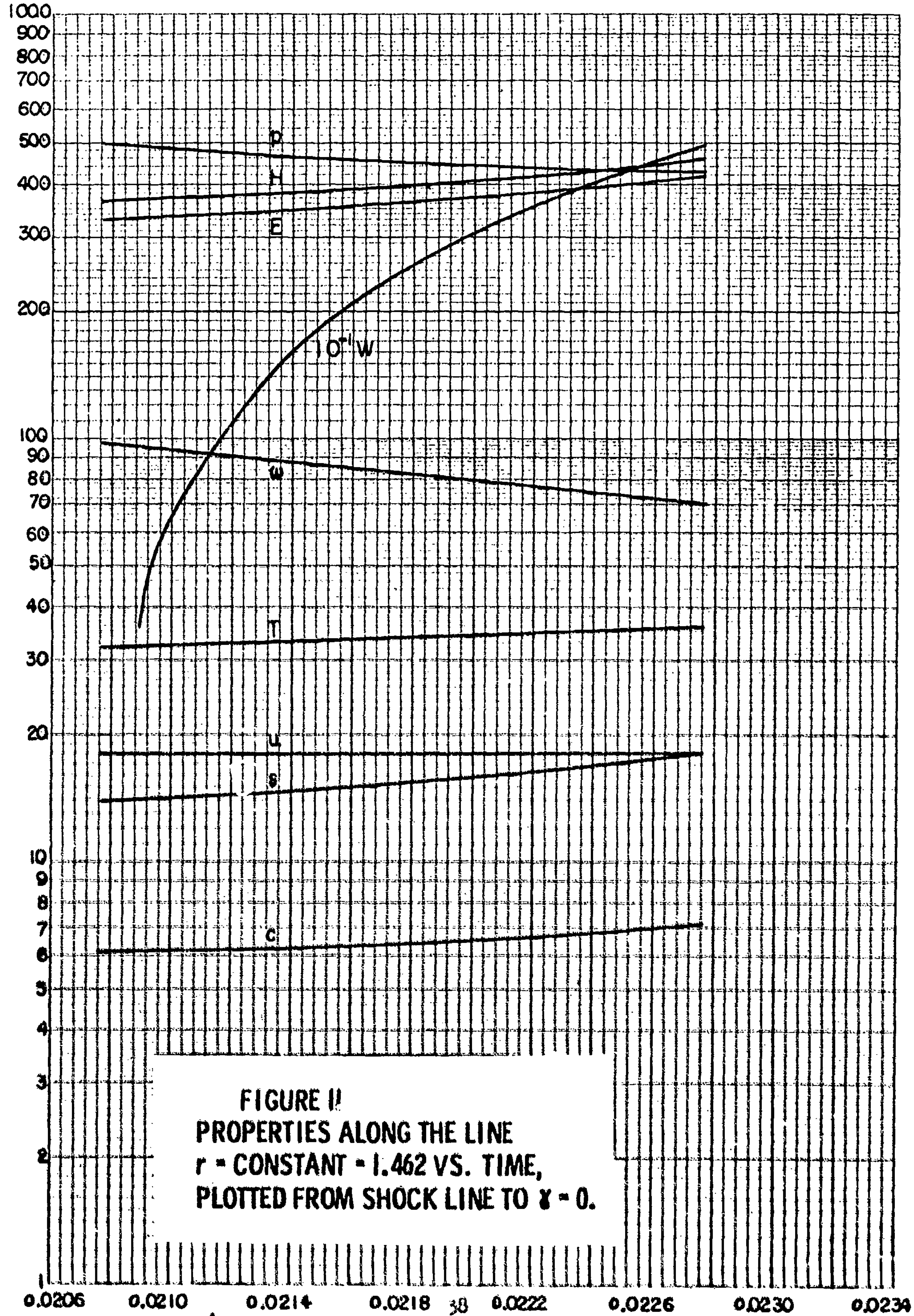


FIGURE 11
PROPERTIES ALONG THE LINE
r = CONSTANT = 1.462 VS. TIME,
PLOTTED FROM SHOCK LINE TO χ = 0.

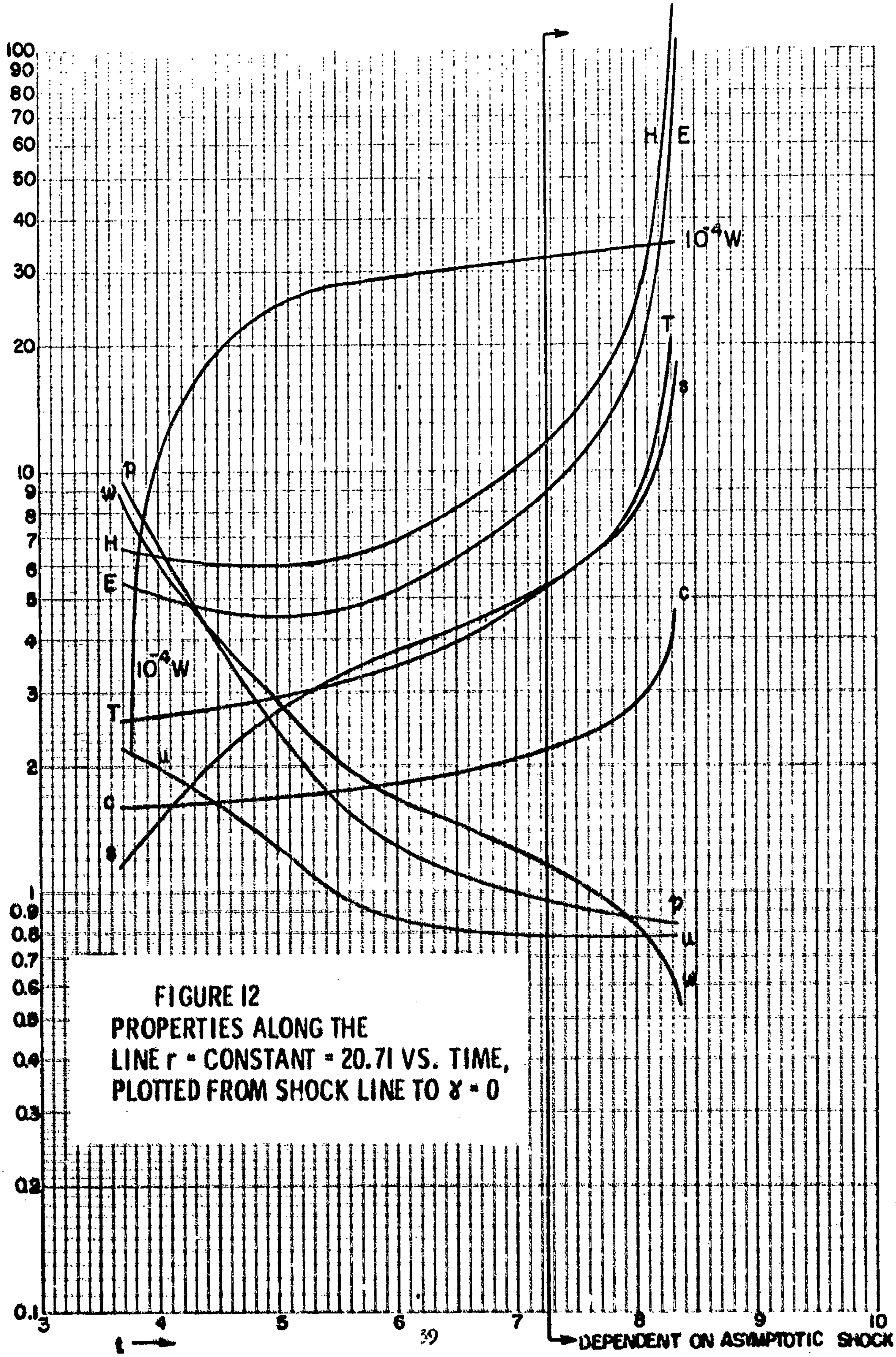


FIGURE 12
PROPERTIES ALONG THE
LINE r = CONSTANT = 20.71 VS. TIME,
PLOTTED FROM SHOCK LINE TO $\gamma = 0$

TABLE I-A

SHOCK-LINE PARAMETERS FOR SPHERICAL PENTOLITE, COMPUTED FROM HUGONIOT EQUATIONS AND CURVE FITTED TO EXPERIMENTAL DATA ON p AND U

α or γ	t	r-1	10^{-3}m	p	u	10^2 s	c-1	ω-1.4	T-1	H	E	U-1
0	0	0	0	818.4	23.16	1802	6.644	128.8	38.85	584.5	537.1	24.24
1	0.0006080	0.01527	0.00002171	803.0	22.94	1784	6.570	127.3	38.47	573.5	526.9	24.00
2	0.003448	0.08482	0.0001291	739.4	22.01	1709	6.274	121.2	36.95	528.2	485.0	23.00
3	0.006742	0.1622	0.0002659	678.4	21.07	1635	5.992	115.1	35.50	484.6	444.6	22.00
4	0.01064	0.2499	0.0004446	619.7	20.12	1561	5.722	108.8	34.10	442.6	405.5	21.00
5	0.01526	0.3492	0.0006794	563.6	19.17	1488	5.463	102.5	32.71	402.6	368.2	20.00
6	0.02077	0.4620	0.0009918	510.1	18.22	1416	5.212	96.25	31.33	364.4	332.6	19.00
7	0.02395	0.5247	0.001187	484.3	17.74	1380	5.091	93.14	30.62	345.9	315.4	18.50
8	0.02743	0.5917	0.001415	459.2	17.26	1344	4.970	90.04	29.91	327.9	298.6	18.00
9	0.03127	0.6637	0.001682	434.7	16.78	1309	4.848	86.93	29.18	310.4	282.3	17.50
10	0.03552	0.7412	0.001997	410.9	16.31	1274	4.721	83.77	28.43	293.6	266.6	17.00
11	0.04022	0.8247	0.002368	387.8	15.83	1238	4.599	80.69	27.67	277.0	351.2	16.50
12	0.04543	0.9146	0.002808	365.4	15.35	1202	4.484	77.76	26.87	261.0	236.4	16.00
13	0.05126	1.012	0.003335	343.6	14.87	1167	4.376	75.02	26.04	245.4	221.8	15.50
14	0.05775	1.118	0.003965	322.6	14.40	1132	4.266	72.34	25.16	230.4	208.0	15.00
15	0.06504	1.232	0.004725	302.2	13.93	1099	4.150	69.67	24.24	215.9	194.7	14.50
16	0.07319	1.357	0.005641	282.6	13.46	1064	4.025	66.97	23.28	201.9	181.7	14.00
17	0.08237	1.492	0.006755	263.7	12.99	1030	3.894	64.36	22.26	188.4	169.4	13.50
18	0.09274	1.640	0.008117	245.5	12.52	994.2	3.761	61.88	21.20	175.3	157.4	13.00
19	0.1045	1.801	0.009792	228.0	12.06	958.6	3.621	59.46	20.12	162.8	146.1	12.50
20	0.1179	1.979	0.01186	211.2	11.60	922.4	3.474	57.00	19.02	150.8	135.3	12.00
21	0.1333	2.175	0.01446	195.0	11.14	885.7	3.321	54.44	17.94	139.3	124.8	11.50
22	0.1509	2.391	0.01773	179.5	10.68	848.5	3.164	51.78	16.92	128.2	114.7	11.00
23	0.1716	2.633	0.02191	164.5	10.22	811.0	3.009	49.01	15.94	117.5	105.1	10.50
24	0.1955	2.902	0.02726	150.2	9.751	773.4	2.858	46.17	15.03	107.3	95.71	10.00
25	0.2238	3.206	0.03426	136.4	9.279	735.5	2.714	43.30	14.13	97.43	86.73	9.500
26	0.2573	3.549	0.04347	123.2	8.804	697.4	2.576	40.45	13.25	88.04	78.14	9.000
27	0.2721	3.696	0.04785	118.2	8.613	682.1	2.522	39.33	12.91	84.41	74.81	8.800
28	0.2882	3.852	0.05285	113.2	8.423	666.8	2.469	38.20	12.56	80.86	71.57	8.600
29	0.3056	4.017	0.05847	108.3	8.232	651.6	2.417	37.09	12.21	77.38	68.39	8.400
30	0.3239	4.187	0.06467	103.6	8.040	636.4	2.366	35.98	11.86	73.97	65.27	8.200
31	0.3439	4.370	0.07179	98.90	7.849	621.1	2.315	34.89	11.50	70.64	62.23	8.000

TABLE I-A. (Continued)

α or γ	t	r-1	10^{-3}m	p	u	10^{2}s	c-1	ω-1.4	T-1	H	E	U-1
32	0.3653	4.560	0.07975	94.35	7.658	605.8	2.265	33.82	11.15	67.39	59.27	7.800
33	0.3883	4.760	0.08870	89.90	7.467	590.5	2.215	32.77	10.79	64.22	56.38	7.600
34	0.4130	4.970	0.09884	85.37	7.276	575.0	2.166	31.73	10.43	61.12	53.38	7.400
35	0.4397	5.191	0.1103	81.35	7.086	559.6	2.117	30.72	10.06	58.11	50.83	7.200
36	0.4684	5.424	0.1233	77.24	6.896	544.0	2.067	29.72	9.690	55.17	48.17	7.300
37	0.4995	5.669	0.1380	73.24	6.707	528.5	2.016	28.74	9.320	52.32	45.60	6.800
38	0.5329	5.927	0.1546	69.36	6.519	512.8	1.965	27.77	8.943	49.54	43.11	6.600
39	0.5691	6.198	0.1736	65.59	6.331	497.1	1.913	26.83	8.567	46.85	40.69	6.400
40	0.6082	6.484	0.1951	61.94	6.145	481.3	1.860	25.92	8.189	44.24	38.37	6.200
41	0.6507	6.785	0.2197	58.39	5.958	465.4	1.808	25.02	7.812	41.71	36.11	6.000
42	0.6968	7.103	0.2478	54.95	5.772	449.2	1.756	24.12	7.438	39.25	33.92	5.800
43	0.7471	7.440	0.2801	51.61	5.586	432.8	1.703	23.22	7.066	36.87	31.81	5.600
44	0.8018	7.796	0.3171	48.38	5.399	416.2	1.650	22.32	6.699	34.55	29.75	5.400
45	0.8619	8.174	0.3599	45.24	5.212	399.4	1.595	21.41	6.337	32.31	27.77	5.200
46	0.9276	8.575	0.4092	42.21	5.025	388.2	1.540	20.48	5.983	30.15	25.85	5.000
47	0.9996	9.000	0.4661	39.29	4.838	364.8	1.481	19.55	5.635	28.06	23.98	4.800
48	1.079	9.451	0.5322	36.48	4.653	347.4	1.421	18.64	5.293	26.06	22.24	4.600
49	1.166	9.929	0.6087	33.78	4.468	329.9	1.360	17.74	4.958	24.13	20.55	4.400
50	1.262	10.44	0.6976	31.18	4.283	312.3	1.298	16.85	4.629	22.27	18.93	4.200
51	1.369	10.98	0.8026	28.69	4.099	294.7	1.236	15.97	4.308	20.50	17.39	4.000
52	1.427	11.27	0.8616	27.48	4.006	285.7	1.202	15.51	4.140	19.63	16.59	3.900
53	1.488	11.57	0.9256	26.30	3.914	276.8	1.174	15.09	3.995	18.79	15.90	3.800
54	1.552	11.87	0.9949	25.15	3.822	267.9	1.142	14.66	3.842	17.96	15.19	3.700
55	1.620	12.19	1.070	24.02	3.730	259.0	1.111	14.22	3.691	17.16	14.49	3.600
56	1.694	12.52	1.153	22.92	3.638	250.0	1.079	13.80	3.544	16.37	13.81	3.500
57	1.771	12.86	1.243	21.84	3.546	241.0	1.048	13.37	3.398	15.60	13.15	3.400
58	1.852	13.22	1.341	20.79	3.454	231.9	1.016	12.94	3.255	14.85	12.50	3.300
59	1.939	13.59	1.449	19.77	3.362	222.8	0.9840	12.52	3.114	14.12	11.87	3.200
60	2.033	13.98	1.567	18.76	3.269	213.7	0.9520	12.09	2.976	13.40	11.26	3.100
61	2.132	14.38	1.697	17.79	3.177	204.5	0.9200	11.66	2.839	12.71	10.66	3.000
62	2.238	14.80	1.840	16.84	3.084	195.3	0.8880	11.23	2.706	12.03	10.08	2.900
63	2.353	15.24	1.998	15.91	2.991	186.2	0.8550	10.80	2.570	11.37	9.493	2.800
64	2.476	15.70	2.174	15.01	2.898	177.0	0.8240	10.38	2.447	10.72	8.958	2.700
65	2.608	16.19	2.368	14.14	2.805	167.9	0.7930	9.960	2.321	10.10	8.422	2.600
66	2.752	16.70	2.585	13.29	2.712	158.7	0.7620	9.570	2.198	9.492	7.906	2.500
67	2.907	17.23	2.827	12.46	2.618	149.5	0.7290	9.130	2.077	8.901	7.405	2.400

TABLE I-A. (Continued)

α or γ	t	r-1	10^{-3}m	p	u	10^{2}z	c-1	ω-1.4	T-1	H	E	U-1
68	3.077	17.80	3.101	11.66	2.525	140.2	0.6970	8.710	1.958	8.332	6.921	2.300
69	3.260	18.40	3.404	10.89	2.431	131.1	0.6640	8.292	1.843	7.779	6.451	2.200
70	3.462	19.03	3.750	10.14	2.336	122.1	0.6320	7.878	1.731	7.242	5.996	2.100
71	3.685	19.71	4.145	9.410	2.241	113.2	0.6000	7.458	1.622	6.723	5.557	2.000
72	3.929	20.43	4.582	8.713	2.146	104.4	0.5690	7.048	1.515	6.223	5.134	1.900
73	4.201	21.21	5.109	8.036	2.050	95.63	0.5370	6.637	1.411	5.740	4.726	1.800
74	4.504	22.04	5.706	7.385	1.954	86.96	0.5060	6.229	1.309	5.276	4.335	1.700
75	4.844	22.94	6.401	6.758	1.857	78.47	0.4760	5.827	1.211	4.828	3.962	1.600
76	5.228	23.92	7.220	6.155	1.759	70.12	0.4450	5.422	1.115	4.398	3.596	1.500
77	5.664	24.99	8.189	5.577	1.660	62.03	0.4140	5.018	1.022	3.984	3.249	1.400
78	6.166	26.16	9.353	5.023	1.560	54.28	0.3830	4.620	0.9320	3.588	2.919	1.300
79	6.746	27.47	10.77	4.494	1.459	46.83	0.3530	4.223	0.8460	3.210	2.602	1.200
80	7.425	28.93	12.52	3.988	1.356	39.61	0.3250	3.832	0.7640	2.848	2.299	1.100
81	8.248	30.62	14.75	3.500	1.250	32.73	0.2990	3.450	0.6860	2.500	2.009	1.000
82	9.225	32.52	17.58	3.045	1.145	26.46	0.2680	3.066	0.6080	2.176	1.741	0.9000
83	1.043	34.74	21.31	2.613	1.037	20.74	0.2376	2.688	0.5320	1.867	1.487	0.8000
84	11.95	37.41	26.43	2.205	0.9265	15.58	0.2076	2.316	0.4580	1.575	1.247	0.7000
85	13.94	40.69	33.80	1.820	0.8125	11.07	0.1781	1.951	0.3880	1.300	1.023	0.6000
86	20.62	50.63	64.22	1.120	0.5724	4.270	0.1201	1.250	0.2547	0.8000	0.6181	0.4000
87	33.15	67.00	146.7	0.6282	0.3617	1.175	0.07392	0.7225	0.1533	0.4487	0.3392	0.2403
88	49.94	87.00	318.0	0.3874	0.2397	0.3572	0.04842	0.4526	0.09918	0.2767	0.2058	0.1541
89	69.43	109.0	621.1	0.2666	0.1718	0.1345	0.03454	0.3141	0.07027	0.1904	0.1402	0.1084
90	87.68	129.0	1025	0.2065	0.1359	0.06742	0.02728	0.2442	0.05529	0.1475	0.1080	0.08486
91	106.3	149.0	1575	0.1682	0.1125	0.03829	0.02251	0.1994	0.04552	0.1201	0.08760	0.06964

TABLE I-B

SHOCK-LINE PARAMETERS FOR SPHERICAL PENTOLITE, COMPUTED FROM HUGONIOT EQUATIONS AND KIRKWOOD-BRINKLEY'S ASYMPTOTIC SHOCK-FRONT DECAY CURVE

α or γ	t	r-1	10^{-6}m	10^3P	10^3u	10^6s	10^3(c-1)	10^3(ω-1.4)	10^3(T-1)	10^3H	10^3E	10^3(U-1)
92	125.1	169.0	2.293	141.8	95.62	237.7	19.15	168.4	38.68	101.3	73.64	59.01
93	144.0	189.0	3.201	122.5	83.25	157.5	16.67	145.8	33.62	87.51	63.50	51.19
94	153.1	209.0	4.322	107.9	73.71	109.6	14.76	128.4	29.73	77.04	55.60	45.20
95	182.3	229.0	5.678	96.33	66.13	79.36	13.24	114.8	26.65	68.81	49.77	40.46
96	201.5	249.0	7.292	87.02	59.96	59.27	12.00	103.8	24.14	62.16	44.91	36.62
97	220.9	269.0	9.185	79.35	54.84	45.42	10.97	94.69	22.07	56.68	40.92	33.45
98	240.2	289.0	11.380	72.91	54.53	35.57	10.11	87.04	20.32	52.08	37.57	30.78
99	259.7	309.0	13.90	67.44	46.84	28.36	9.371	80.54	18.83	48.17	34.72	28.50
100	279.1	329.0	16.77	62.72	43.64	22.97	8.731	74.93	17.54	44.80	32.27	26.53
101	298.6	349.0	20.01	58.61	48.05	18.86	8.173	70.04	16.41	41.87	30.15	24.61
102	327.9	379.0	25.61	53.36	37.27	14.34	7.456	63.79	14.97	38.12	27.42	22.61
103	357.3	409.0	32.16	48.96	34.26	11.15	6.854	58.55	13.75	34.97	25.15	20.17
104	386.7	439.0	39.75	45.22	31.70	8.833	6.340	54.10	12.72	32.30	23.22	19.20
105	416.2	469.0	48.45	42.01	29.48	7.11	5.897	50.26	11.83	29.93	21.48	17.64
106	445.7	499.0	58.33	39.21	27.55	5.61	5.511	46.92	11.05	28.01	20.12	16.67
107	475.2	529.0	69.48	36.76	25.85	4.80	5.171	44.00	10.37	26.26	18.85	15.63
108	504.7	559.0	81.95	34.59	24.35	4.01	4.870	41.40	9.764	24.71	17.73	14.72
109	534.3	589.0	95.84	32.66	23.01	3.38	4.602	39.10	9.225	23.33	16.74	13.90
110	563.9	619.0	111.20	30.92	21.80	2.88	4.361	37.03	8.741	22.09	15.85	13.17
111	593.5	649.0	128.20	29.36	20.72	2.47	4.143	35.16	8.304	20.97	15.05	12.51
112	628.1	679.0	150.0	27.73	19.57	2.09	3.946	33.21	7.908	19.81	14.20	11.81
113	652.8	709.0	167.0	26.66	18.83	1.86	3.766	31.93	7.547	19.05	13.65	11.36
114	682.5	739.0	189.1	25.49	18.01	1.63	3.602	30.53	7.217	18.20	13.05	10.86
115	722.2	769.0	213.0	24.41	17.25	1.43	3.451	29.24	6.914	17.43	12.50	10.41
116	741.9	799.0	238.9	23.41	16.56	1.26	3.312	28.05	6.635	16.72	11.99	9.980
117	781.5	839.0	276.6	22.21	15.71	1.08	3.143	26.60	6.295	15.86	11.36	9.470
118	821.1	879.0	318.0	21.11	14.95	0.93	2.989	25.30	5.988	15.08	10.81	9.010
119	860.8	919.0	363.4	20.12	14.25	0.81	2.850	24.11	5.708	14.37	10.30	8.590
120	900.4	995.0	412.9	19.22	13.61	0.70	2.723	23.03	5.453	13.73	9.832	8.200
121	940.1	999.0	466.7	18.39	13.03	0.62	2.606	22.04	5.220	13.13	9.404	7.850
122	969.7	1049.	540.2	17.44	12.37	0.52	2.474	20.91	4.954	12.46	8.930	7.450
123	1039.	1099.	621.1	16.59	11.77	0.45	2.354	19.89	4.713	11.85	8.485	7.090

TABLE I-B (Continued)

α or γ	t	r-1	$10^{-6}m$	$10^{3}p$	$10^{3}u$	$10^{6}s$	$10^{3}(c-1)$	$10^{3}(\alpha-1.4)$	$10^{3}(T-1)$	$10^{3}H$	$10^{3}E$	$10^{3}(U-1)$
124	1089	1149	709.7	15.82	11.22	0.40	2.244	18.96	4.494	11.30	8.089	6.760
125	1139	1199	806.4	15.11	10.72	0.34	2.144	18.11	4.293	10.79	7.726	6.450
126	1238	1299	1025	13.86	9.843	0	1.969	16.62	3.941	9.901	7.088	5.920
127	1338	1399	1281	12.80	9.095	↓	1.819	15.35	3.641	9.144	6.545	5.470
128	1437	1499	1575	11.89	8.449		1.690	14.26	3.383	8.492	6.078	5.080
129	1537	1599	1911	11.10	8.888		1.578	13.30	3.158	7.925	5.663	4.740
130	1636	1699	2293	10.40	7.395		1.479	12.47	2.960	7.427	5.312	4.450
131	1736	1799	2722	9.782	6.958		1.392	11.73	2.785	6.987	5.001	4.180
132	1835	1899	3201	9.233	6.569		1.314	11.07	2.629	6.595	4.721	3.950
133	1935	1999	3733	8.741	6.220		1.244	10.48	2.490	6.243	4.467	3.740
134	2034	2099	4322	8.297	5.906		1.181	9.951	2.364	5.927	4.237	3.550
135	2134	2199	4969	7.896	5.621		1.124	9.469	2.250	5.640	4.034	3.380
136	2234	2299	5678	7.530	5.361		1.072	9.031	2.146	5.379	3.848	3.220
137	2334	2399	6451	7.196	5.124		1.025	8.631	2.051	5.140	3.675	3.080
138	2533	2599	8202	6.608	4.707		0.9414	7.926	1.884	4.720	3.377	2.830
139	2732	2799	10,240	6.107	4.351		0.8702	7.325	1.741	4.362	3.119	2.610
140	2932	2999	12,600	5.675	4.044		0.8088	6.807	1.618	4.054	2.895	2.430
141	3131	3199	15,290	5.299	3.776		0.7553	6.356	1.511	3.785	2.704	2.270
142	3331	3399	18,340	4.968	3.541		0.7082	5.960	1.417	3.549	2.535	2.130
143	3531	3599	21,770	4.676	3.333		0.6666	5.609	1.334	3.340	2.382	2.000
144	3730	3799	25,610	4.415	3.148		0.6295	5.296	1.259	3.154	2.260	1.890
145	3930	3999	29,870	4.181	2.981		0.5962	5.016	1.193	2.987	2.135	1.790
146	4129	4199	34,570	3.970	2.831		0.5662	4.763	1.133	2.836	2.023	1.700
147	4529	4599	45,420	3.605	2.571		0.5143	4.325	1.029	2.575	1.842	1.540
148	4928	4999	58,330	3.301	2.354		0.4706	3.960	0.9419	2.358	1.686	1.410
149	5328	5399	73,480	3.042	2.170		0.4341	3.650	0.8683	2.173	1.577	1.300
150	5727	5799	91,050	2.821	2.012		0.4025	3.384	0.8051	2.015	1.441	1.210
151	6127	6199	111,200	2.629	1.876		0.3751	3.154	0.7504	1.878	1.336	1.113
152	6526	6599	134,200	2.461	1.756		0.3511	2.952	0.7024	1.758	1.257	1.050
153	6926	6999	160,100	2.312	1.650		0.3300	2.774	0.6601	1.652	1.181	0.9900
154	7326	7399	189,100	2.180	1.556		0.3112	2.616	0.6225	1.557	1.116	0.9300
155	7725	7799	221,500	2.063	1.472		0.2944	2.475	0.5889	1.473	1.055	0.8800
156	8125	8199	257,300	1.956	1.396		0.2793	2.347	0.5586	1.397	0.9970	0.8400

TABLE II. PARAMETERS ON CONSTANT α 'S

(FIRST ROW OF EACH α REPRESENTS SHOCK-LINE VALUES, AND LAST ROW REPRESENTS VALUES ON THE CONTACT SURFACE.)

α	γ	t	r	10^{-3}m	p	u	s	c	ω	T	10^{-3}W	H	E
0	0	0	1.00	0	818	23.2	18.0	7.64	130	39.9	0	584	537
1	1	0.000608	1.02	0.0000217	803	22.9	17.8	7.57	129	39.5	0	574	527
	0	0.000443	1.01	0	802	23.0	18.0	7.63	128	39.7	0.105	580	533
2	2	0.00345	1.09	0.000129	739	22.0	17.1	7.27	123	38.0	0	528	485
	1	0.00268	1.06	0.0000217	735	22.3	17.8	7.51	119	39.0	0.486	555	509
	0	0.00251	1.06	0	734	22.3	18.0	7.56	118	39.3	0.588	561	514
3	3	0.00674	1.16	0.000266	678	21.1	16.4	6.99	117	36.5	0	485	445
	2	0.00584	1.14	0.000129	674	21.4	17.1	7.21	113	37.5	0.567	510	467
	1	0.00507	1.12	0.0000217	670	21.6	17.8	7.44	109	38.5	1.04	535	490
	0	0.00491	1.11	0	669	21.7	18.0	7.50	108	38.8	1.13	541	495
4	4	0.0106	1.25	0.000445	620	20.1	15.6	6.72	110	35.1	0	443	405
	3	0.0956	1.22	0.000266	615	20.4	16.4	6.93	106	36.1	0.674	467	428
	2	0.0867	1.20	0.000129	612	20.7	17.1	7.15	103	37.0	1.22	491	449
	1	0.0792	1.18	0.0000217	609	20.9	17.8	7.38	99.8	38.1	1.67	516	471
	0	0.0776	1.18	0	608	20.9	18.0	7.43	99.1	38.3	1.76	521	476
5	5	0.0153	1.35	0.000679	564	19.2	14.9	6.46	104	33.7	0	403	368
	4	0.0140	1.32	0.000445	560	19.5	15.6	6.66	100	34.7	0.800	426	389
	3	0.0129	1.29	0.000266	557	19.7	16.4	6.87	97.1	35.6	1.45	449	410
	2	0.0120	1.26	0.000129	554	19.9	17.1	7.08	94.0	36.6	1.97	472	431
	1	0.0113	1.24	0.0000217	551	20.1	17.8	7.31	91.1	37.6	2.40	496	452
	0	0.0111	1.24	0	551	20.2	18.0	7.36	90.4	37.8	2.49	501	457
6	6	0.0208	1.46	0.000992	550	18.2	14.2	6.21	97.7	32.3	0	364	333
	5	0.0192	1.42	0.000679	507	18.5	14.9	6.40	94.2	33.3	0.959	386	353
	4	0.0179	1.39	0.000445	504	18.8	15.6	6.60	91.1	34.2	1.73	408	373
	3	0.0169	1.36	0.000266	502	19.0	16.4	6.81	88.2	35.2	2.35	431	393
	2	0.0160	1.34	0.000129	499	19.2	17.1	7.02	85.4	36.1	2.85	453	413
	1	0.0153	1.32	0.0000217	497	19.3	17.8	7.24	82.9	37.1	3.26	476	433
	0	0.0152	1.32	0	497	19.4	18.0	7.29	82.3	37.3	3.35	481	438
7	7	0.0239	1.55	0.00119	484	17.7	13.8	6.09	94.5	31.6	0	346	315
	6	0.0230	1.50	0.000992	483	17.9	14.2	6.18	92.8	32.1	0.560	357	325
	5	0.0215	1.47	0.000679	480	18.2	14.9	6.38	89.5	33.1	1.50	378	345
	4	0.0202	1.43	0.000445	477	18.4	15.6	6.57	86.5	34.0	2.25	400	364

TABLE II. PARAMETERS ON CONSTANT α °S (Continued)

α	γ	t	r	10^{-3}m	p	u	s	c	ω	T	10^{-3}W	H	E
	3	0.0192	1.41	0.000266	475	18.6	16.4	6.78	83.8	34.9	2.85	422	384
	2	0.0183	1.39	0.000129	473	18.8	17.1	6.98	81.2	35.9	3.34	444	404
	1	0.0176	1.37	0.0000217	471	18.9	17.8	7.20	78.8	36.8	3.75	466	423
	0	0.0175	1.36	0	471	19.0	18.0	7.26	78.3	37.1	3.84	471	428
8	8	0.0274	1.59	0.00142	459	17.3	13.4	5.97	91.4	30.9	0	328	299
	7	0.0264	1.57	0.00119	458	17.4	13.8	6.06	89.7	31.4	0.615	338	301
	6	0.0255	1.55	0.000992	456	17.6	14.2	6.16	88.1	31.9	1.16	349	318
	5	0.0240	1.51	0.000679	453	17.8	14.9	6.35	85.0	32.8	2.08	370	337
	4	0.0227	1.48	0.000445	451	18.0	15.6	6.54	82.2	33.8	2.81	391	356
	3	0.0217	1.45	0.000266	449	18.2	16.4	6.74	79.6	34.7	3.40	413	375
	2	0.0208	1.43	0.000129	447	18.4	17.1	6.95	77.2	35.6	3.88	434	394
	1	0.0202	1.42	0.0000217	446	18.5	17.8	7.17	74.9	36.6	4.28	456	414
	0	0.0200	1.41	0	446	18.6	18.0	7.22	74.4	36.8	4.36	461	419
9	9	0.0313	1.66	0.00168	435	16.8	13.1	5.85	88.3	30.2	0	310	282
	8	0.0302	1.64	0.00142	433	16.9	13.4	5.94	86.7	30.7	0.680	321	292
	7	0.0292	1.62	0.00119	432	17.1	13.8	6.03	85.1	31.2	1.28	331	301
	6	0.0283	1.59	0.000992	431	17.2	14.2	6.13	83.6	31.7	1.81	341	310
	5	0.0267	1.56	0.000679	428	17.4	14.9	6.32	80.7	32.7	2.71	362	329
	4	0.0255	1.53	0.000445	426	17.7	15.6	6.51	78.0	33.5	3.42	382	347
	3	0.0245	1.50	0.000266	424	17.8	16.4	6.71	75.5	34.5	4.00	403	366
	2	0.0236	1.48	0.000129	423	18.0	17.1	6.91	73.2	35.4	4.47	424	385
	1	0.0230	1.47	0.0000217	421	18.1	17.8	7.13	71.1	36.3	4.86	446	404
	0	0.0228	1.46	0	421	18.2	18.0	7.18	70.6	36.6	4.94	451	409
10	10	0.0355	1.74	0.00200	411	16.3	12.7	5.72	85.2	29.4	0	294	267
	5	0.0298	1.61	0.000679	405	17.1	14.9	6.29	76.5	32.4	3.40	353	321
	0	0.0259	1.52	0	398	17.7	18.0	7.15	67.0	36.3	5.58	451	399
15	15	0.0650	2.23	0.00473	302	13.9	11.0	5.15	71.1	25.2	0	216	195
	10	0.0563	2.06	0.00200	299	14.6	12.7	5.58	63.6	28.3	5.04	259	233
	5	0.0509	1.95	0.000679	296	15.1	14.9	6.13	57.4	31.2	8.01	312	281
	0	0.0475	1.88	0	294	15.5	18.0	6.95	50.6	35.0	9.95	392	352
20	20	0.118	2.98	0.0119	311	11.6	9.22	4.47	58.4	20.0	0	151	135
	15	0.102	2.71	0.00473	210	12.3	11.0	4.99	50.9	23.9	9.15	186	166
	10	0.0938	2.57	0.00200	208	12.7	12.7	5.43	45.6	27.1	13.5	224	200
	5	0.0891	2.48	0.000679	207	13.0	14.9	5.95	41.3	30.0	16.0	271	241
	0	0.0862	2.43	0	207	13.2	18.0	6.74	36.6	33.6	17.7	345	307

TABLE II. PARAMETERS ON CONSTANT α 'S (Continued)

α	γ	t	r	$10^{-3}m$	p	u	s	c	ϖ	T	$10^{-3}W$	H	E
25	25	0.224	4.21	0.0343	136	9.28	7.36	3.71	44.7	15.1	0	97.4	86.7
	20	0.191	3.76	0.0119	136	9.94	9.22	4.29	39.2	18.6	18.4	126	112
	15	0.176	3.54	0.00473	135	10.3	11.0	4.82	34.2	22.5	26.0	156	137
	10	0.169	3.44	0.00200	135	10.5	12.7	5.26	30.7	25.7	29.6	188	166
	5	0.165	3.37	0.000679	135	10.7	14.9	5.75	27.7	28.6	31.8	231	204
	0	0.163	3.34	0	135	10.8	18.0	6.51	24.7	32.0	33.3	300	265
30	30	0.324	5.19	0.0647	104	8.04	6.36	3.37	37.4	12.9	0	74.0	65.3
	25	0.290	4.79	0.0343	103	8.43	7.36	3.63	34.8	14.5	17.6	87.0	76.8
	20	0.258	4.39	0.0119	103	8.92	9.22	4.18	30.5	17.8	33.9	113	99.1
	15	0.245	4.21	0.00473	103	9.18	11.0	4.71	26.7	21.5	40.7	140	122
	10	0.238	4.12	0.00200	103	9.31	12.7	5.15	23.9	24.8	44.0	170	148
	5	0.235	4.07	0.000679	103	9.39	14.9	5.64	21.6	27.8	46.0	211	185
	0	0.233	4.04	0	103	9.44	18.0	6.37	19.2	31.0	47.4	277	244
35	35	0.440	6.19	0.110	81.4	7.09	5.60	3.12	32.1	11.1	0	58.1	50.8
	30	0.399	5.77	0.0647	81.6	7.40	6.36	3.30	30.2	12.4	19.9	66.9	58.6
	25	0.365	5.40	0.0343	81.5	7.71	7.36	3.55	28.0	14.0	35.7	78.6	68.9
	20	0.335	5.04	0.0119	81.1	8.08	9.22	4.08	24.6	17.1	50.4	102	89.3
	15	0.322	4.88	0.00473	81.9	8.26	11.0	4.62	21.6	20.8	56.6	127	111
	10	0.316	4.81	0.00200	81.0	8.35	12.7	5.05	19.3	24.0	59.6	156	136
	5	0.313	4.77	0.000679	81.1	8.40	14.9	5.54	17.4	27.0	61.5	196	171
	0	0.311	4.74	0	81.2	8.44	18.0	6.25	15.5	30.2	62.8	260	228
40	40	0.608	7.48	0.195	61.9	6.15	4.81	2.86	27.3	9.19	0	44.2	38.4
	35	0.546	6.91	0.110	62.4	6.45	5.60	3.05	25.4	10.6	27.6	51.9	45.0
	30	0.505	6.51	0.0647	62.6	6.69	6.36	3.23	23.8	11.9	45.1	59.7	51.8
	25	0.472	6.18	0.0343	62.6	6.93	7.36	3.47	22.0	13.5	59.1	70.2	61.0
	20	0.443	5.86	0.0119	62.6	7.18	9.22	3.98	19.5	16.5	72.2	92.0	79.7
	15	0.431	5.73	0.00473	62.6	7.30	11.0	4.53	17.2	19.9	77.9	116	99.5
	10	0.426	5.67	0.00200	62.6	7.36	12.7	4.96	15.3	23.3	80.6	143	123
	5	0.423	5.63	0.000679	62.7	7.40	14.9	5.44	13.7	26.3	82.4	182	157
	0	0.422	5.61	0	62.8	7.42	18.0	6.12	12.2	29.4	83.6	244	213
45	45	0.862	9.17	0.360	45.2	5.21	3.99	2.60	22.8	7.34	0	32.3	27.8
	40	0.765	8.39	0.195	45.7	5.51	4.81	2.79	21.0	8.69	38.2	38.7	33.2
	35	0.701	7.85	0.110	46.0	5.75	5.60	2.97	19.4	10.0	62.0	45.4	38.9
	30	0.660	7.49	0.0647	46.2	5.93	6.36	3.15	18.1	11.3	77.3	52.3	44.8

TABLE II. PARAMETERS ON CONSTANT α'S (Continued)

α	γ	t	r	10^{-3}m	p	u	s	c	ω	T	10^{-3}W	H	E
	25	0.628	7.19	0.0343	46.4	6.09	7.36	3.38	16.8	12.9	89.5	62.0	53.1
	20	0.600	6.91	0.0119	46.5	6.26	9.22	3.87	14.9	15.7	101	82.1	70.5
	15	0.589	6.80	0.00473	46.6	6.34	11.0	4.41	13.2	19.0	106	104	89.1
	10	0.584	6.75	0.00200	46.7	6.37	12.7	4.85	11.7	22.4	109	131	112
	5	0.582	6.72	0.000679	46.7	6.39	14.9	5.32	10.5	25.4	110	168	144
	0	0.580	6.70	0	46.8	6.40	18.0	5.98	9.33	28.5	112	228	198
50	50	1.26	11.4	0.698	31.2	4.28	3.12	2.30	18.3	5.63	0	22.3	18.9
	45	1.10	10.3	0.630	31.7	4.57	3.99	2.51	16.8	6.83	52.3	27.4	23.3
	40	0.997	9.59	0.195	32.1	4.80	4.81	2.70	15.4	8.11	84.4	33.0	27.9
	35	0.931	9.08	0.110	32.3	4.97	5.60	2.89	14.2	9.42	105	38.8	32.8
	30	0.890	8.75	0.0647	32.5	5.10	6.36	3.06	13.3	10.7	118	45.0	38.0
	25	0.858	8.48	0.0343	32.7	5.21	7.36	3.29	12.3	12.3	128	53.8	45.5
	20	0.830	8.24	0.0119	32.9	5.31	9.22	3.75	10.9	15.0	130	72.6	61.6
	15	0.820	8.14	0.00473	33.0	5.36	11.0	4.28	9.75	18.0	143	93.4	79.2
	10	0.816	8.10	0.00200	33.0	5.38	12.7	4.73	8.60	21.4	145	118	100
45	5	0.813	8.07	0.000679	33.1	5.39	14.9	5.19	7.68	24.5	147	154	131
	0	0.812	8.06	0	33.1	5.39	18.0	5.83	6.81	27.6	148	212	184
55	55	1.62	13.2	1.07	24.0	3.73	2.59	2.11	15.6	4.70	0	17.2	14.5
	50	1.47	12.3	0.698	24.4	3.91	3.12	2.24	14.8	5.34	41.5	19.8	16.7
	45	1.30	11.2	0.360	24.8	4.15	3.99	2.46	13.6	6.50	87.6	24.5	20.6
	40	1.19	10.5	0.195	25.1	4.34	4.81	2.64	12.5	7.73	116	29.5	24.7
	35	1.12	9.99	0.110	25.3	4.48	5.60	2.83	11.5	9.02	134	34.9	29.2
	30	1.08	9.67	0.0647	25.5	4.58	6.36	3.01	10.7	10.3	146	40.7	34.0
	25	1.05	9.42	0.0343	25.6	4.66	7.36	3.22	9.90	11.8	156	49.0	41.1
	20	1.02	9.20	0.0119	25.8	4.74	9.22	3.67	8.78	14.5	165	67.0	56.5
	15	1.01	9.11	0.00473	25.9	4.77	11.0	4.18	7.90	17.3	169	87.0	73.5
	10	1.01	9.07	0.00200	26.0	4.78	12.7	4.65	6.96	20.7	172	111	93.7
	5	1.00	9.04	0.000679	26.0	4.79	14.9	5.10	6.18	23.9	173	145	124
	0	1.00	9.03	0	26.0	4.79	18.0	5.73	5.48	26.9	174	203	175
60	60	2.03	15.0	1.57	18.8	3.27	2.14	1.95	13.5	3.98	0	13.4	11.3
	55	1.85	14.0	1.07	19.0	3.41	2.59	2.06	12.9	4.44	41.5	15.4	12.9
	50	1.69	13.1	0.698	19.3	3.57	3.12	2.19	12.2	5.07	78.2	17.7	14.8
	45	1.51	12.0	0.360	19.7	3.78	3.99	2.40	11.1	6.19	119	22.0	18.3

TABLE II. PARAMETERS ON CONSTANT α 'S (Continued)

α	γ	t	r	10^{-3}m	p	u	s	c	ω	T	10^{-3}W	H	E
	40	1.40	11.3	0.195	19.9	3.90	4.81	2.59	10.2	7.39	145	26.7	22.1
	35	1.33	10.9	0.110	20.1	4.05	5.60	2.77	9.48	8.65	161	31.7	26.2
	30	1.29	10.6	0.0647	20.3	4.13	6.36	2.95	8.81	9.91	172	37.2	30.8
	25	1.25	10.3	0.0343	20.4	4.19	7.36	3.17	8.11	11.5	181	45.1	37.4
	20	1.23	10.1	0.0119	20.6	4.25	9.22	3.60	7.18	14.0	190	62.4	52.3
	15	1.22	10.0	0.00473	20.7	4.27	11.0	4.10	6.48	16.7	194	81.8	68.8
	10	1.21	9.99	0.00200	20.7	4.28	12.7	4.57	5.71	20.1	196	105	88.2
	5	1.21	9.97	0.000679	20.7	4.29	14.9	5.02	5.05	23.3	197	138	117
	0	1.21	9.96	0	20.7	4.29	18.0	5.64	4.47	26.3	198	194	168
65	65	2.61	17.2	2.37	14.1	2.81	1.68	1.79	11.4	3.32	0	10.1	8.42
	60	2.35	16.0	1.57	14.4	2.95	2.14	1.90	10.9	3.75	48.2	11.7	9.77
	55	2.15	15.0	1.07	14.7	3.07	2.59	2.00	10.4	4.22	84.1	13.5	11.2
	50	1.98	[illegible]	0.698	14.9	3.20	3.12	2.12	9.84	4.79	116	15.6	12.9
	45	1.78	13.0	0.360	15.2	3.38	3.99	2.34	8.98	5.87	152	19.6	16.1
	40	1.67	12.3	0.195	15.4	3.52	4.81	2.53	8.26	7.03	175	23.9	19.6
	35	1.59	11.9	0.110	15.6	3.61	5.60	2.72	7.64	8.26	190	28.5	23.4
	30	1.55	11.6	0.0647	15.7	3.67	6.36	2.89	7.09	9.50	200	33.7	27.6
	25	1.51	11.4	[illegible]	15.8	3.71	7.36	3.11	6.51	11.1	208	41.2	33.9
	20	1.49	11.2	0.0119	16.0	3.75	9.22	3.52	5.75	13.6	217	57.9	48.2
	15	1.48	11.1	0.00473	16.0	3.77	11.0	4.00	5.20	16.1	220	76.6	64.2
	10	1.47	11.0	0.00200	[illegible]	3.78	12.7	4.49	4.60	19.4	222	98.8	82.8
	5	1.47	11.0	0.000679	16.1	3.78	14.9	4.93	4.04	22.7	224	131	111
	0	1.47	11.0	0	16.1	3.78	18.0	5.55	3.58	25.7	225	186	160
70	70	3.46	20.0	[illegible]	10.1	2.34	1.22	1.63	9.28	2.73	0	7.24	6.00
	65	3.05	[illegible]	2.37	10.4	2.46	1.68	1.73	8.93	3.11	56.4	8.64	7.14
	60	2.76	17.1	1.57	10.7	2.60	2.14	1.83	8.53	3.50	97.0	10.1	8.28
	55	2.55	16.1	1.07	10.9	2.71	2.59	1.93	8.17	3.94	128	11.6	9.52
	50	2.36	15.2	0.698	11.0	2.82	3.12	2.06	7.72	4.49	155	13.5	11.0
	45	2.14	14.2	0.360	11.3	2.96	3.99	2.26	7.04	5.51	187	17.1	13.9
	40	2.02	13.5	0.195	11.5	3.07	4.81	2.46	6.40	6.64	207	21.0	17.0
	35	1.94	13.0	0.110	11.6	3.13	5.60	2.65	5.99	7.83	221	25.4	20.5

TABLE II. PARAMETERS ON CONSTANT α'S (Continued)

α	γ	t	r	10^{-3}m	p	u	s	c.	ω	T	10^{-3}W	H	E
	30	1.89	12.8	0.0647	11.7	3.18	6.36	2.83	5.55	9.05	230	30.2	24.4
	25	1.86	12.5	0.0343	11.8	3.21	7.36	3.04	5.08	10.6	237	37.4	30.4
	20	1.83	12.3	0.0119	11.9	3.24	9.22	3.44	4.47	13.1	245	53.4	44.2
	15	1.82	12.3	0.00473	12.0	3.25	11.0	3.89	4.05	15.4	249	71.3	59.5
	10	1.81	12.2	0.00200	12.0	3.26	12.7	4.40	3.60	18.6	251	92.6	77.3
	5	1.81	12.2	0.000679	12.0	3.26	14.9	4.84	3.14	21.1	252	124	104
	0	1.81	12.2	0	12.0	3.26	18.0	5.44	2.77	25.0	253	177	152
75	75	4.84	23.9	6.40	6.76	1.86	0.785	1.48	7.23	2.21	0	4.83	3.96
	70	4.13	21.5	3.75	7.05	2.00	1.22	1.57	7.03	2.52	65.8	5.94	4.85
	65	3.66	19.7	2.37	7.27	2.12	1.68	1.66	6.75	2.86	111	7.12	5.80
	60	3.32	18.5	1.57	7.45	2.22	2.14	1.76	6.46	3.23	145	8.36	6.78
	55	3.08	17.5	1.07	7.61	2.31	2.59	1.86	6.19	3.64	171	9.74	7.87
	50	2.87	16.5	0.698	7.76	2.40	3.12	1.98	5.85	4.15	194	11.5	9.20
	45	2.63	15.5	0.360	7.96	2.51	3.99	2.19	5.33	5.12	222	14.7	11.7
	40	2.49	14.8	0.195	8.12	2.59	4.81	2.39	4.92	6.21	240	18.3	14.6
	35	2.41	14.4	0.110	8.24	2.64	5.60	2.58	4.55	7.35	252	22.3	17.7
	30	2.36	14.1	0.0647	8.32	2.67	6.36	2.76	4.21	8.54	260	26.8	21.4
	25	2.32	13.9	0.0343	8.40	2.69	7.36	2.97	3.83	10.1	267	33.5	26.9
	20	2.29	13.7	0.0119	8.48	2.71	9.22	3.35	3.35	12.6	274	48.8	40.0
	15	2.27	13.6	0.00473	8.51	2.72	11.0	3.78	3.04	14.7	278	65.9	54.8
	10	2.27	13.6	0.00200	8.53	2.72	12.7	4.29	2.72	17.7	280	86.2	71.9
	5	2.27	13.6	0.000679	8.54	2.72	14.9	4.74	2.36	21.2	281	116	97.6
	0	2.27	13.6	0	8.54	2.72	18.0	5.32	2.07	24.3	282	167	144
80	80	7.43	29.9	12.5	3.99	1.36	0.397	1.33	5.23	1.76	0	2.85	2.30
	75	5.93	25.8	6.40	4.29	1.51	0.785	1.40	5.20	2.00	76.4	3.67	2.96
	70	5.07	23.2	3.75	4.49	1.63	1.22	1.49	5.06	2.28	126	4.60	3.70
	65	4.51	21.4	2.37	4.65	1.73	1.68	1.59	4.87	2.59	162	5.61	4.49
	60	4.12	20.0	1.57	4.79	1.81	2.14	1.68	4.66	2.93	190	6.69	5.31
	55	3.83	19.0	1.07	4.91	1.87	2.59	1.78	4.47	3.32	211	7.89	6.25
	50	3.58	18.1	0.698	5.03	1.94	3.12	1.90	4.23	3.79	231	9.39	7.40
	45	3.31	17.0	0.360	5.19	1.02	3.99	2.10	3.87	4.69	255	12.2	9.58
	40	3.16	16.4	0.195	5.31	1.07	4.81	2.30	3.56	5.71	271	15.5	12.1
	35	3.06	15.9	0.110	5.40	1.10	5.60	2.49	3.29	6.80	282	19.2	15.0
	30	3.00	15.7	0.0647	5.47	1.12	6.36	2.67	3.04	7.96	289	23.3	18.3
	25	2.96	15.4	0.0343	5.53	1.14	7.36	2.89	2.76	9.50	296	29.6	23.5

TABLE II. PARAMETERS ON CONSTANT α 'S (Continued)

α	γ	t	r	10^{-3}m	p	u	s	c	ω	T	10^{-3}W	H	E
	20	2.92	15.2	0.0119	5.59	1.14	9.22	3.25	2.39	12.0	302	44.1	35.8
	15	2.91	15.2	0.00473	5.61	1.15	11.0	3.65	2.17	14.0	306	60.0	50.0
	10	2.90	15.1	0.00200	5.62	1.15	12.7	4.15	1.96	16.7	307	79.5	66.2
	5	2.90	15.1	0.00679	5.63	1.15	14.9	4.62	1.69	20.3	308	108	90.5
	0	2.90	15.1	0	5.63	1.15	18.0	5.18	1.47	23.5	309	157	135
85	85	13.9	41.7	33.8	1.82	0.813	0.111	1.18	3.35	1.39	0	1.30	1.02
	80	9.46	32.3	12.5	2.13	0.987	0.397	1.24	3.51	1.55	85.8	1.87	1.46
	75	7.54	27.9	6.40	2.31	1.11	0.785	1.32	3.48	1.75	137	2.52	1.98
	70	6.44	25.1	3.75	2.44	1.20	1.22	1.40	3.38	2.01	174	3.28	2.57
	65	5.73	23.2	2.37	2.55	1.27	1.68	1.50	3.26	2.29	202	4.12	3.21
	60	5.23	21.8	1.57	2.65	1.33	2.14	1.59	3.13	2.60	225	5.03	3.89
	55	4.87	20.7	1.07	2.74	1.37	2.59	1.68	3.00	2.95	242	6.06	4.68
	50	4.56	19.7	0.698	2.85	1.42	3.12	1.80	2.85	3.39	260	7.35	5.65
	45	4.23	18.6	0.360	2.95	1.47	3.99	1.99	2.61	4.22	280	9.83	7.53
	40	4.03	17.9	0.195	3.05	1.49	4.81	2.19	2.41	5.16	295	12.7	9.77
	35	3.92	17.5	0.110	3.12	1.51	5.60	2.38	2.23	6.19	305	16.0	12.3
	30	3.85	17.2	0.0647	3.18	1.51	6.36	2.57	2.06	7.30	311	19.8	15.3
	25	3.79	17.0	0.0343	3.22	1.52	7.56	2.79	1.86	8.80	317	25.6	20.0
	20	3.75	16.8	0.0119	3.27	1.51	9.22	3.15	1.60	11.3	323	39.1	31.5
	15	3.73	16.7	0.00473	3.29	1.51	11.0	3.51	1.45	13.2	327	54.6	45.0
	10	3.72	16.6	0.00200	3.30	1.51	12.7	3.91	1.32	15.5	328	72.5	60.2
	5	3.72	16.6	0.000679	3.30	1.51	14.9	4.49	1.13	19.3	329	99.1	82.8
	0	3.72	16.6	0	3.31	1.50	18.0	5.03	0.983	22.5	330	146	125
87	87	33.2	68.0	147	0.628	0.512	0.0118	1.07	2.12	1.15	0	0.449	0.339
	85	17.5	44.1	33.8	0.914	0.546	0.111	1.11	2.40	1.24	73.9	0.756	0.583
	80	11.8	34.3	12.5	1.08	0.679	0.397	1.17	2.48	1.38	129	1.18	0.912
	75	9.42	29.6	6.40	1.19	0.766	0.785	1.25	2.45	1.56	168	1.71	1.31
	70	8.04	26.7	3.75	1.28	0.831	1.22	1.33	2.38	1.79	199	2.34	1.79
	65	7.15	24.7	2.37	1.35	0.880	1.68	1.42	2.29	2.05	223	3.06	2.32
	60	6.53	23.2	1.57	1.42	0.917	2.14	1.51	2.20	2.33	243	3.84	2.90
	55	6.08	22.1	1.07	1.49	0.945	2.59	1.61	2.12	2.66	259	4.74	3.57

TABLE II. PARAMETERS OF CONSTANT α 'S (Continued)

α	γ	t	r	10^{-3}m	p	u	s	c	ω	T	10^{-3}W	H	E
	50	5.69	21.1	0.698	1.56	0.969	3.12	1.71	2.01	3.06	274	5.88	4.42
	45	5.28	19.9	0.360	1.65	0.993	3.99	1.90	1.84	3.82	294	8.01	6.07
	40	5.03	19.1	0.195	1.72	1.00	4.81	2.10	1.70	4.70	307	10.7	8.07
	35	4.89	18.7	0.110	1.77	1.00	5.60	2.29	1.57	5.67	316	13.7	10.4
	30	4.80	18.4	0.0647	1.81	0.999	6.36	2.47	1.45	6.72	323	17.1	13.1
	25	4.74	18.1	0.0343	1.85	0.993	7.36	2.70	1.31	8.19	328	22.5	17.3
	20	4.68	17.9	0.0119	1.88	0.983	9.22	3.05	1.11	10.7	334	33.3	28.1
	15	4.66	17.8	0.00473	1.90	0.976	11.0	3.39	1.01	12.5	337	50.0	41.0
	10	4.65	17.7	0.00200	1.90	0.973	12.7	3.84	0.922	14.6	339	66.9	55.6
	5	4.64	17.7	0.000679	1.91	0.971	14.9	4.37	0.792	18.3	340	92.0	76.7
	0	4.64	17.7	0	1.91	0.969	18.0	4.90	0.681	21.7	341	137	117
89	89	69.4	110	621	0.267	0.172	0.00135	1.03	1.71	1.07	0	0.190	0.140
	87	37.1	69.2	147	0.421	0.277	0.0118	1.05	1.89	1.11	38.6	0.308	0.229
	85	20.0	45.3	33.8	0.610	0.435	0.111	1.09	2.07	1.18	96.9	0.551	0.421
	80	13.8	35.4	12.5	0.725	0.548	0.397	1.14	2.11	1.31	145	0.920	0.700
	75	11.1	30.8	6.40	0.796	0.624	0.785	1.21	2.07	1.48	181	1.39	1.05
	70	9.62	27.9	3.75	0.861	0.677	1.22	1.29	2.00	1.69	210	1.97	1.49
	65	8.65	25.9	2.37	0.913	0.717	1.68	1.38	1.92	1.94	234	2.64	1.98
	60	7.97	24.4	1.57	0.960	0.748	2.14	1.47	1.83	2.20	253	3.36	2.51
	55	7.48	23.3	1.07	1.00	0.771	2.59	1.56	1.76	2.51	268	4.19	3.13
	50	7.06	22.2	0.698	1.05	0.791	3.12	1.67	1.66	2.89	283	5.25	3.91
	45	6.61	21.1	0.360	1.11	0.811	3.99	1.85	1.51	3.61	302	7.33	5.45
	40	6.35	20.3	0.195	1.16	0.820	4.81	2.04	1.39	4.45	315	9.78	7.33
	35	6.19	19.8	0.110	1.19	0.823	5.60	2.23	1.28	5.37	324	12.6	9.50
	30	6.09	19.5	0.0647	1.21	0.324	6.36	2.41	1.17	6.38	330	15.9	12.0
	25	6.02	19.3	0.0343	1.23	0.822	7.36	2.64	1.05	7.81	336	20.9	16.1
	20	5.96	19.0	0.0119	1.25	0.819	9.22	3.00	0.885	10.4	342	33.2	26.3
	15	5.94	18.9	0.00473	1.25	0.816	11.0	3.32	0.796	12.2	345	47.4	38.7
	10	5.93	18.9	0.00200	1.26	0.815	12.7	3.74	0.730	14.1	346	63.8	53.0
	5	5.92	18.8	0.000679	1.26	0.814	14.9	4.29	0.630	17.7	347	87.9	73.2
	0	5.92	18.8	0	1.26	0.814	18.0	4.82	0.537	21.2	348	132	112

TABLE II. PARAMETERS ON CONSTANT α 'S (Continued)

α	γ	t	r	$10^{-3}m$	p	u	s	c	ω	T	$10^{-3}W$	H	E
91	91	106	150	1580	0.168	0.112	0.000383	1.02	1.60	1.05	0	0.120	0.0876
	89	72.0	110	621	0.226	0.152	0.00135	1.03	1.66	1.06	15.8	0.155	0.111
	87	38.9	69.7	147	0.356	0.250	0.0118	1.04	1.81	1.09	49.9	0.262	0.194
	85	21.3	45.8	33.8	0.515	0.399	0.111	1.08	1.97	1.16	105	0.488	0.372
	80	15.0	36.1	12.5	0.612	0.504	0.397	1.13	1.99	1.28	152	0.835	0.633
	75	12.3	31.4	6.40	0.668	0.577	0.785	1.20	1.94	1.45	188	1.29	0.969
	70	10.7	28.6	3.75	0.718	0.627	1.22	1.28	1.87	1.65	216	1.85	1.38
	65	9.74	26.6	2.37	0.760	0.665	1.68	1.36	1.78	1.89	239	2.48	1.85
	60	9.06	25.2	1.57	0.796	0.695	2.14	1.45	1.70	2.15	258	3.18	2.36
	55	8.56	24.1	1.07	0.828	0.718	2.59	1.54	1.62	2.45	273	3.99	2.96
	50	8.14	23.1	0.698	0.861	0.738	3.12	1.65	1.53	2.82	288	5.01	3.72
	45	7.68	21.9	0.360	0.906	0.761	3.99	1.83	1.38	3.52	307	7.03	5.22
	40	7.42	21.2	0.195	0.938	0.773	4.81	2.02	1.27	4.34	320	9.41	7.04
	35	7.26	20.7	0.110	0.960	0.780	5.60	2.20	1.16	5.24	329	12.2	9.15
	30	7.16	20.4	0.0647	0.975	0.783	6.36	2.39	1.06	6.23	335	15.3	11.6
	25	7.09	20.1	0.0343	0.987	0.785	7.36	2.62	0.952	7.65	340	20.3	15.5
	20	7.02	19.9	0.0119	0.998	0.786	9.22	2.98	0.795	10.2	346	32.3	25.6
	15	7.00	19.8	0.00473	1.00	0.787	11.0	3.29	0.713	12.0	349	46.4	37.8
	10	6.99	19.7	0.00200	1.01	0.787	12.7	3.70	0.654	13.8	351	62.5	51.9
	5	6.98	19.7	0.000679	1.01	0.787	14.9	4.26	0.566	17.4	352	86.1	71.8
	0	6.98	19.7	0	1.01	0.786	18.0	4.79	0.481	21.0	352	130	110

TABLE III

PARAMETERS ON CONSTANT γ's

(FIRST ROW OF EACH γ REPRESENTS SHOCK-LINE VALUES, AND LAST ROW REPRESENTS VALUES ON THE SOUND PATH α = 91 BOUNDING THE EXPERIMENTAL DOMAIN.)

$\begin{pmatrix} \gamma \\ s \\ 10^{-3}m \end{pmatrix}$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
$\begin{pmatrix} 0 \\ 18.0 \\ 0 \end{pmatrix}$	0	0	1.00	818	23.2	7.64	130	39.9	0	585	537
	5	0.0111	1.24	551	20.2	7.36	90.4	37.8	2.49	501	457
	10	0.0259	1.52	398	17.7	7.15	67.0	36.3	5.58	441	399
	15	0.0475	1.88	294	15.5	6.95	50.6	35.0	9.95	392	352
	20	0.0862	2.45	207	13.2	6.74	36.6	33.6	17.7	345	307
	25	0.163	3.34	135	10.8	6.51	24.7	32.0	33.3	300	265
	30	0.233	4.04	103	9.44	6.37	19.2	31.0	47.4	277	244
	35	0.311	4.74	81.2	8.44	6.25	15.5	30.2	62.8	260	228
	40	0.422	5.61	62.8	7.42	6.12	12.2	29.4	83.6	244	213
	45	0.580	6.70	46.8	6.40	5.98	9.33	28.5	112	228	198
	50	0.812	8.06	33.1	5.39	5.83	6.81	27.6	148	212	184
	55	1.00	9.03	26.0	4.79	5.73	5.48	26.9	174	203	175
	60	1.21	9.96	20.7	4.29	5.64	4.47	26.3	198	194	166
	65	1.47	11.0	16.1	3.78	5.55	3.58	25.7	225	186	160
	70	1.81	12.2	12.0	3.26	5.44	2.77	25.0	253	177	152
	75	2.27	13.6	8.54	2.72	5.32	2.07	24.3	282	167	144
	80	2.90	15.1	5.63	2.15	5.18	1.47	23.5	309	157	135
	85	3.72	16.6	3.31	1.50	5.03	0.985	22.5	330	146	125
	87	4.54	17.7	1.91	0.969	4.90	0.681	21.7	341	137	117
	89	5.92	18.8	1.26	0.814	4.82	0.537	21.2	348	[illegible]	112
	91	6.98	19.7	1.01	0.786	4.79	0.481	21.0	352	130	[illegible]

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

$\begin{pmatrix} \gamma \\ s \\ 10^{-3}m \end{pmatrix}$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
$\begin{pmatrix} 5 \\ 14.9 \\ 0.000679 \end{pmatrix}$	5	0.153	1.39	564	19.2	6.46	104	33.7	0	403	368
	6	0.0192	1.42	507	18.5	6.40	94.2	33.3	0.959	386	353
	7	0.0215	1.47	479	18.2	6.38	89.5	33.1	1.50	378	345
	8	0.0240	1.51	453	17.8	6.35	85.0	32.8	2.08	370	337
	9	0.0267	1.56	428	17.4	5.32	80.7	32.6	2.71	362	329
	10	0.0298	1.61	405	17.1	6.29	76.5	32.4	2.40	353	321
	15	0.0509	1.95	296	15.1	6.13	57.4	31.2	8.01	312	281
	20	0.0891	2.48	207	13.0	5.95	41.3	30.0	16.0	271	241
	25	0.165	3.37	135	10.7	5.75	27.7	28.6	31.8	231	204
	30	0.235	4.07	103	9.39	5.64	21.6	27.7	46.0	211	185
	35	0.313	4.77	81.1	8.40	5.54	17.4	27.0	61.5	196	171
	40	0.423	5.63	62.7	7.40	5.44	13.7	26.3	82.4	182	157
	45	0.582	6.72	46.6	6.39	5.32	10.5	25.4	110	168	144
	50	0.813	8.07	33.1	5.39	5.19	7.68	24.5	147	154	131
	55	1.00	9.04	26.0	4.79	5.10	6.18	23.9	173	145	124
	60	1.21	9.97	20.7	4.29	5.02	5.05	23.3	197	138	117
	65	1.47	11.0	16.1	3.78	4.93	4.04	22.7	224	131	111
	70	1.81	12.2	12.0	3.26	4.84	3.14	22.0	252	124	104
	75	2.27	13.6	8.54	2.72	4.74	2.36	21.2	281	116	97.6
	80	2.90	15.1	5.63	2.15	4.62	1.69	20.3	308	108	90.5
	85	3.72	16.6	3.30	1.51	4.49	1.13	19.3	329	99.2	82.8
	87	4.64	17.7	1.91	0.971	4.37	0.792	18.3	340	92.0	76.7
	89	5.92	18.8	1.26	0.814	4.29	0.630	17.7	347	87.9	73.2
	91	6.98	19.7	1.01	0.787	4.26	0.564	17.4	352	86.1	71.8

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

$\begin{pmatrix} \gamma \\ s \\ 10^{-3}m \end{pmatrix}$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
$\begin{pmatrix} 10 \\ 12.7 \\ 0.00200 \end{pmatrix}$	10	0.355	1.74	411	16.3	5.72	85.2	29.4	0	294	267
	15	0.0563	2.06	299	14.6	5.58	65.6	28.3	5.04	259	233
	20	0.0938	2.57	208	12.7	5.43	45.6	27.1	13.5	224	200
	25	0.169	3.44	135	10.5	5.26	30.7	25.7	29.6	188	166
	30	0.238	4.12	103	9.31	5.15	23.9	24.8	44.0	170	148
	35	0.316	4.81	81.0	8.35	5.06	19.3	24.0	59.6	156	136
	40	0.426	5.67	62.6	7.36	4.96	15.3	23.3	80.6	143	123
	45	0.584	6.75	46.7	6.37	4.85	11.7	22.4	109	131	112
	50	0.816	8.10	33.0	5.38	4.73	8.60	21.4	145	118	100
	55	1.01	9.07	26.0	4.78	4.65	6.96	20.7	172	111	93.7
	60	1.21	9.99	20.7	4.28	4.57	5.71	20.1	196	105	88.2
	65	1.47	11.0	16.1	3.78	4.49	4.60	19.4	222	98.8	82.8
	70	1.81	12.2	12.0	3.26	4.40	3.60	18.6	251	92.6	77.4
	75	2.27	13.6	8.53	2.72	4.29	2.72	17.7	280	86.2	71.9
	80	2.90	15.1	5.62	2.15	4.15	1.96	16.7	307	79.5	66.2
	85	3.72	16.6	3.30	1.51	3.99	1.32	15.5	328	72.5	60.2
	87	4.65	17.7	1.90	0.973	3.84	0.922	14.6	339	66.9	55.6
	89	5.93	18.9	1.26	0.815	3.74	0.730	14.1	346	63.8	53.0
	91	6.99	19.7	1.01	0.787	3.70	0.654	13.8	351	62.5	51.9

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

$\begin{pmatrix} \gamma \\ s \\ 10^{-3}m \end{pmatrix}$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
$\begin{pmatrix} 15 \\ 11.0 \\ 0.00473 \end{pmatrix}$	15	0.0650	2.23	302	13.9	5.15	71.1	25.2	0	216	195
	20	0.102	2.71	210	12.3	4.99	50.9	23.9	9.15	186	166
	25	0.176	3.54	135	10.3	4.82	34.2	22.5	26.0	156	137
	30	0.245	[illegible].21	103	9.18	4.71	26.7	21.5	40.7	140	122
	35	0.322	4.88	81.0	8.26	4.62	21.6	20.8	56.6	127	111
	40	0.431	5.73	62.6	7.30	4.53	17.2	19.9	77.9	116	99.5
	45	0.589	6.80	46.6	6.34	4.41	13.2	19.0	106	104	89.1
	50	0.820	8.14	33.0	5.36	4.28	9.75	18.0	143	93.4	79.2
	55	1.01	9.11	25.9	4.77	4.18	7.90	17.3	169	87.0	73.5
	60	1.22	10.0	20.7	4.27	4.10	6.48	16.7	194	81.8	68.8
	65	1.48	11.1	16.0	3.77	4.00	5.20	16.1	220	76.6	64.2
	70	1.82	12.3	12.0	3.25	3.89	4.05	15.4	249	71.3	59.5
	75	2.27	13.6	8.51	2.72	3.78	3.04	14.7	278	65.9	54.8
	80	2.91	15.2	5.61	2.15	3.65	2.17	14.0	306	60.4	50.0
	85	3.73	16.7	3.29	1.51	3.51	1.45	13.2	327	54.6	45.0
	87	4.66	17.8	1.89	0.976	3.39	1.01	12.5	337	50.0	41.0
	89	5.94	18.9	1.25	0.816	3.32	0.796	12.2	345	47.4	38.7
	91	7.00	19.8	1.00	0.787	3.29	0.713	12.0	349	46.4	37.8

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

$\begin{pmatrix} \gamma \\ 10^{-3}m \end{pmatrix}$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
$\begin{pmatrix} 20 \\ 9.22 \\ 0.0119 \end{pmatrix}$	20	0.118	2.98	211	11.6	4.47	58.4	20.0	0	151	135
	25	0.191	3.76	136	9.94	4.29	39.2	18.6	18.4	126	112
	30	0.258	4.39	103	8.92	4.18	30.5	17.8	33.9	113	99.1
	35	0.335	5.04	81.1	8.08	4.08	24.6	17.1	50.4	102	89.3
	40	0.443	5.86	62.6	7.18	3.98	19.5	16.5	72.2	92.0	79.7
	45	0.600	6.91	46.5	6.26	3.87	14.9	15.7	101	82.1	70.5
	50	0.830	8.24	32.9	5.31	3.75	10.9	15.0	138	72.6	61.6
	55	1.02	9.20	25.8	4.74	3.67	8.78	14.5	165	67.0	56.5
	60	1.23	10.1	20.6	4.25	3.60	7.18	14.0	190	62.4	52.3
	65	1.49	11.2	16.0	3.75	3.52	5.75	13.6	217	57.9	48.2
	70	1.83	12.3	11.9	3.24	3.44	4.47	13.1	245	53.4	44.2
	75	2.29	13.7	8.48	2.71	3.35	3.35	12.6	274	48.8	40.0
	80	2.92	15.2	5.59	2.14	3.25	2.39	12.0	302	44.1	35.8
	85	3.75	16.8	3.27	1.51	3.15	1.60	11.3	323	39.1	31.5
	87	4.68	17.9	2.88	0.983	3.05	1.11	10.7	334	35.3	28.1
	89	5.96	19.0	1.25	0.819	3.00	0.885	10.4	342	33.2	26.3
	91	7.02	19.9	1.00	0.786	2.98	0.795	10.2	346	32.3	25.6

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

γ, s, $10^{-3}m$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
25	25	0.224	4.21	136	9.28	3.71	44.7	15.1	0	97.4	86.7
7.36	30	0.290	4.79	103	8.43	3.63	34.8	14.5	17.6	87.0	76.8
0.0343	35	0.365	5.40	81.5	7.71	3.55	28.0	14.0	35.7	78.6	68.9
	40	0.472	6.18	62.6	6.93	3.47	22.0	13.5	59.1	70.3	61.0
	45	0.628	7.19	46.4	6.09	3.38	16.8	12.9	89.5	62.0	53.1
	50	0.858	8.48	32.7	5.21	3.29	12.3	12.3	128	53.8	45.5
	55	1.05	9.42	25.6	4.66	3.22	9.90	11.8	156	49.0	41.1
	60	1.25	10.3	20.4	4.19	3.17	8.11	11.5	181	45.1	37.4
	65	1.51	11.4	15.8	3.71	3.11	6.51	11.1	208	41.2	33.9
	70	1.86	12.5	11.8	3.21	3.04	5.08	10.6	237	37.4	30.4
	75	2.32	13.9	8.40	2.69	2.97	3.83	10.1	267	33.5	26.9
	80	2.96	15.4	5.53	2.14	2.89	2.76	9.50	296	29.6	23.5
	85	3.79	17.0	3.22	1.52	2.79	1.86	8.80	317	25.6	20.0
	87	4.74	18.1	1.85	0.993	2.70	1.31	8.19	328	22.5	17.3
	89	6.02	19.3	1.23	0.822	2.64	1.05	7.81	336	20.9	16.1
	91	7.09	20.1	0.987	0.785	2.62	0.952	7.65	340	20.3	15.5
30	30	0.324	5.19	104	8.04	3.37	37.3	12.9	0	74.0	65.3
6.36	35	0.399	5.77	81.6	7.40	3.30	30.2	12.4	19.9	66.9	58.6
0.0647	40	0.505	6.51	62.6	6.69	3.23	23.8	11.9	45.1	59.7	51.8
	45	0.660	7.49	46.2	5.93	3.15	18.1	11.3	77.3	52.3	44.8
	50	0.890	8.75	32.5	5.10	3.06	13.3	10.7	118	45.0	38.0
	55	1.08	9.67	25.5	4.58	3.01	10.7	10.3	146	40.7	34.0
	60	1.29	10.6	20.3	4.13	2.95	8.81	9.91	172	37.2	30.8
	65	1.55	11.6	15.7	3.67	2.89	7.09	9.50	200	33.7	27.6
	70	1.89	12.8	11.7	3.18	2.83	5.55	9.05	230	30.2	24.4
	75	2.36	14.1	8.32	2.67	2.76	4.21	8.54	260	26.8	21.4
	80	3.00	15.7	5.47	2.12	2.67	3.04	7.96	289	23.3	18.3
	85	3.85	17.2	3.18	1.51	2.57	2.06	7.30	311	19.8	15.3
	87	4.80	18.4	1.81	0.999	2.47	1.45	6.72	323	17.2	13.1
	89	6.10	19.5	1.21	0.824	2.41	1.17	6.38	330	15.9	12.0
	91	7.16	20.4	0.975	0.783	2.39	1.06	6.23	335	15.3	11.6

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

$\begin{pmatrix} \gamma \\ s \\ 10^{-3}m \end{pmatrix}$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
$\begin{pmatrix} 35 \\ 5.60 \\ 0.110 \end{pmatrix}$	35	0.440	6.19	81.4	7.09	3.12	32.1	11.1	0	58.1	50.8
	40	0.546	6.91	62.4	6.45	3.05	25.4	10.6	27.6	51.9	45.0
	45	0.701	7.85	46.0	5.75	2.97	19.4	10.0	62.0	45.4	38.9
	50	0.931	9.08	32.3	4.97	2.89	14.2	9.42	105	38.8	32.8
	55	1.12	9.99	25.3	4.48	2.83	11.5	9.02	134	34.9	29.2
	60	1.33	10.9	20.1	4.05	2.77	9.48	8.65	161	31.7	26.2
	65	1.59	11.9	15.6	3.61	2.72	7.64	8.26	190	28.5	23.4
	70	1.94	13.0	11.6	3.13	2.65	5.99	7.83	221	25.4	20.5
	75	2.41	14.4	8.24	2.64	2.58	4.58	7.35	252	22.3	17.7
	80	3.06	15.9	5.40	2.10	2.49	3.29	6.80	282	19.2	15.0
	85	3.92	17.5	3.12	1.51	2.38	2.23	6.19	305	16.0	12.3
	87	4.89	18.7	1.77	1.00	2.29	1.57	5.67	316	13.7	10.4
	89	6.19	19.8	1.19	0.823	2.23	1.28	5.37	324	12.6	9.50
	91	7.26	20.7	0.960	0.780	2.20	1.16	5.24	329	12.2	9.15
$\begin{pmatrix} 40 \\ 4.81 \\ 0.195 \end{pmatrix}$	40	0.608	7.48	61.9	6.15	2.86	27.3	9.19	0	44.2	38.4
	45	0.765	8.39	45.7	5.51	2.79	21.0	8.69	38.2	38.7	33.2
	50	0.997	9.59	32.1	4.80	2.70	15.4	8.11	84.4	33.0	27.9
	55	1.19	10.5	25.1	4.34	2.64	12.5	7.73	116	29.5	24.7
	60	1.40	11.3	19.9	3.94	2.59	10.2	7.39	145	26.7	22.1
	65	1.67	12.2	15.4	3.52	2.53	8.26	7.03	175	23.9	19.6
	70	2.02	13.5	11.5	3.07	2.46	6.48	6.64	207	21.0	17.0
	75	2.49	14.8	8.12	2.59	2.39	4.92	6.21	240	18.3	14.6
	80	3.16	16.4	5.31	2.07	2.30	3.56	5.71	271	15.5	12.1
	85	4.03	17.9	3.05	1.49	2.19	2.41	5.16	294	12.7	9.77
	87	5.03	19.1	1.72	1.00	2.10	1.70	4.70	307	10.7	8.07
	89	6.35	20.3	1.16	0.820	2.04	1.39	4.45	315	9.78	7.33
	91	7.42	21.2	0.938	0.773	2.02	1.27	4.34	320	9.41	7.04

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

$(\gamma,\ s,\ 10^{-3}m)$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
(45, 3.99, 0.360)	45	0.862	9.17	45.2	5.21	2.60	22.8	7.34	0	32.3	27.8
	50	1.10	10.3	31.7	4.57	2.51	16.8	6.83	52.3	27.4	23.3
	55	1.30	11.2	24.8	4.15	2.46	13.6	6.50	87.6	24.5	20.6
	60	1.51	12.0	19.7	3.78	2.40	11.1	6.19	119	22.0	18.3
	65	1.78	13.0	15.2	3.38	2.34	8.98	5.87	152	19.6	16.1
	70	2.14	14.2	11.3	2.96	2.26	7.04	5.51	187	17.1	13.9
	75	2.63	15.5	7.96	2.51	2.19	5.33	5.12	222	14.7	11.7
	80	3.31	17.0	5.19	2.02	2.10	3.87	4.69	255	12.2	9.58
	85	4.23	18.6	2.95	1.47	1.99	2.61	4.22	280	9.83	7.53
	87	5.28	19.9	1.65	0.993	1.90	1.84	3.82	294	8.10	6.07
	89	6.61	21.1	1.11	0.811	1.85	1.51	3.61	302	7.33	5.45
	91	7.68	21.9	0.906	0.761	1.83	1.38	3.52	307	7.03	5.22
50, 3.12, 0.698	50	1.26	11.4	31.2	4.28	2.30	18.3	5.63	0	22.3	18.9
	55	1.47	12.3	24.4	3.91	2.24	14.8	5.34	41.5	19.8	16.7
	60	1.69	13.1	19.3	3.57	2.19	12.2	5.07	78.2	17.7	14.8
	65	1.98	14.1	14.9	3.24	2.12	9.84	4.79	116	15.6	12.9
	70	2.36	15.2	11.0	2.82	2.06	7.72	4.49	155	13.5	11.0
	75	2.87	16.5	7.76	2.40	1.98	5.85	4.15	194	11.5	9.20
	80	2.58	18.1	5.03	1.94	1.90	4.23	3.79	231	9.39	7.40
	85	4.56	19.7	2.83	1.42	1.80	2.85	3.39	260	7.35	5.65
	87	5.69	21.1	1.56	0.969	1.71	2.01	3.06	274	5.88	4.42
	89	7.06	22.2	1.05	0.791	1.67	1.66	2.89	283	5.25	3.91
	91	8.14	23.1	0.861	0.738	1.65	1.53	2.82	288	5.01	3.72

TABLE III. PARAMETERS ON CONSTANT γ'S (Continued)

$(\gamma, s, 10^{-3}m)$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
(55, 2.59, 1.07)	55	1.62	13.2	24.0	3.73	2.11	15.6	4.69	0	17.2	14.5
	60	1.85	14.0	19.0	3.41	2.06	12.9	4.48	41.5	15.4	12.9
	65	2.15	15.0	14.7	3.07	2.00	10.4	4.22	84.1	13.5	11.2
	70	2.55	16.1	10.9	2.71	1.93	8.17	3.94	128	11.6	9.52
	75	3.08	17.5	7.61	2.31	1.86	6.19	3.64	171	9.74	7.87
	80	3.83	19.0	4.91	1.87	1.78	4.47	3.32	211	7.89	6.25
	85	4.87	20.7	2.74	1.37	1.68	3.00	2.95	242	6.06	4.68
	87	6.08	22.1	1.49	0.945	1.60	2.12	2.66	259	4.74	3.57
	89	7.48	23.3	1.00	0.771	1.56	1.76	2.51	268	4.19	3.13
	91	8.56	24.1	0.828	0.718	1.54	1.62	2.45	273	3.99	2.96
60, 2.14, 1.57	60	2.03	15.0	18.8	3.27	1.95	13.5	3.98	0	13.4	11.3
	65	2.35	16.0	14.4	2.95	1.90	10.9	3.75	48.2	11.7	9.77
	70	2.76	17.1	10.7	2.60	1.83	8.53	3.50	97.0	10.1	8.28
	75	3.32	18.5	7.45	2.22	1.76	6.46	3.23	145	8.36	6.78
	80	4.12	20.0	4.79	1.81	1.68	4.66	2.93	190	6.69	5.31
	85	5.23	21.8	2.65	1.33	1.59	3.13	2.60	225	5.03	3.89
	87	6.53	23.2	1.42	0.917	1.51	2.20	2.33	243	3.84	2.90
	89	7.97	24.4	0.960	0.748	1.47	1.83	2.20	253	3.36	2.51
	91	9.06	25.2	0.796	0.695	1.45	1.70	2.15	258	3.18	2.36
65, 1.68, 2.37	65	2.61	17.2	14.1	2.81	1.79	11.4	3.32	0	10.1	8.42
	70	3.05	18.4	10.4	2.48	1.73	8.93	3.11	56.4	8.64	7.14
	75	3.66	19.7	7.27	2.12	1.66	6.75	2.86	111	7.12	5.80
	80	4.51	21.4	4.65	1.73	1.59	4.87	2.59	162	5.61	4.49
	85	5.73	23.2	2.55	1.27	1.50	3.26	2.29	202	4.12	3.21
	87	7.15	24.7	1.35	0.880	1.42	2.29	2.05	223	3.06	2.32
	89	8.65	25.9	0.913	0.717	1.38	1.92	1.94	234	2.64	1.98
	91	9.74	26.6	0.760	0.665	1.36	1.78	1.89	239	2.48	1.85

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

γ / s / $10^{-3}m$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
(70, 1.22, 3.75)	70	3.46	20.0	10.1	2.34	1.63	9.28	2.73	0	7.24	6.00
	75	4.13	21.5	7.05	2.00	1.57	7.03	2.52	65.8	5.94	4.85
	80	5.07	23.2	4.49	1.63	1.49	5.06	2.28	126	4.60	3.70
	85	6.44	25.1	2.44	1.20	1.40	3.38	2.01	174	3.28	2.57
	87	8.04	26.7	1.28	0.831	1.33	2.38	1.79	199	2.34	1.79
	89	9.62	27.9	0.861	0.677	1.29	2.00	1.69	210	1.97	1.49
	91	10.7	28.6	0.718	0.627	1.28	1.87	1.65	216	1.85	1.38
75, 0.785, 6.40	75	4.84	23.9	6.76	1.86	1.48	7.23	2.21	0	4.83	3.96
	80	5.93	25.8	4.29	1.51	1.40	5.20	2.00	76.4	3.67	2.96
	85	7.54	27.9	2.31	1.11	1.32	3.48	1.75	137	2.52	1.98
	87	9.42	29.6	1.19	0.766	1.25	2.45	1.56	168	1.71	1.31
	89	11.1	30.8	0.798	0.624	1.21	2.07	1.48	181	1.39	1.05
	91	12.3	31.4	0.668	0.577	1.20	1.94	1.45	188	1.29	0.969
80, 0.397, 12.5	80	7.43	29.9	3.99	1.36	1.33	5.23	1.76	0	2.85	2.30
	85	9.46	32.3	2.13	0.987	1.24	3.51	1.55	85.8	1.87	1.48
	87	11.8	34.3	1.01	0.679	1.17	2.48	1.38	129	1.18	0.912
	89	13.8	35.4	0.725	0.548	1.14	2.11	1.31	145	0.920	0.700
	91	15.0	36.1	0.612	0.504	1.13	1.99	1.28	152	0.835	0.633
85, 0.111, 33.8	85	13.9	41.7	1.82	0.813	1.18	3.35	1.39	0	1.30	1.02
	87	17.5	44.1	0.914	0.546	1.11	2.40	1.24	73.9	0.756	0.583
	89	20.0	45.3	0.610	0.435	1.09	2.07	1.18	96.9	0.551	0.421
	91	21.3	45.8	0.515	0.399	1.08	1.97	1.16	105	0.488	0.372
87, 0.0118, 147	87	33.2	68.0	0.628	0.362	1.07	2.12	1.15	0	0.449	0.339
	89	37.1	69.2	0.421	0.277	1.05	1.89	1.11	38.6	0.308	0.229
	91	38.9	69.7	0.356	0.250	1.04	1.81	1.09	49.9	0.262	0.194

TABLE III. PARAMETERS ON CONSTANT γ 'S (Continued)

$\begin{pmatrix} \gamma \\ s \\ 10^{-3}m \end{pmatrix}$	α	t	r	p	u	c	ω	T	$10^{-3}W$	H	E
$\begin{pmatrix} 89 \\ 0.00135 \\ 621 \end{pmatrix}$	89 91	69.4 72.0	110 110	0.267 0.226	0.172 0.152	1.03 1.03	1.71 1.66	1.07 1.06	0 15.8	0.190 0.155	0.140 0.111
$\begin{pmatrix} 91 \\ 0.000383 \\ 1580 \end{pmatrix}$	91	106	150	0.168	0.112	1.02	1.60	1.05	0	0.120	0.0876

TABLE IV. PARAMETERS ON CONSTANT r'S

(FIRST ROW OF EACH r REPRESENTS SHOCK-LINE VALUES, AND LAST ROW REPRESENTS VALUES EITHER ON THE SOUND PATH $\alpha = 91$ BOUNDING THE EXPERIMENTAL DOMAIN OR ON THE CONTACT SURFACE $\gamma = 0$.)

r	α	t	$10^{-3}m$	p	u	ε	c	ω	T	$10^{-3}W$	H	E
1.00	0	0	0	818	23.2	18.0	7.64	130	39.9	0	585	537
1.09	2	0.00345	0.000129	739	22.0	17.1	7.27	123	38.0	0	528	485
	(γ=0)	0.00377	0	700	22.0	18.0	7.53	113	39.0	0.874	551	504
1.25	4	0.0106	0.000445	620	20.1	15.6	6.72	110	35.1	0	443	405
	5	0.0115	0.000534	552	20.1	17.6	7.24	92.0	37.3	2.28	489	446
	(γ=0)	0.0116	0	544	20.1	18.0	7.35	89.4	37.8	2.61	499	455
1.46	6	0.0208	0.000992	510	18.2	14.2	6.21	97.7	32.3	0	364	333
	7	0.0214	0.000656	479	18.2	15.0	6.39	89.2	33.2	1.57	380	347
	8	0.0220	0.000323	450	18.2	16.1	6.68	80.4	34.4	3.21	406	369
	(γ=0)	0.0228	0	422	18.2	18.0	7.18	70.7	36.6	4.93	451	409
1.74	10	0.0355	0.00200	411	16.3	12.7	5.72	85.2	29.4	0	294	267
	12	0.0374	0.000797	359	16.2	14.6	6.15	69.3	31.6	4.66	329	298
	(γ=0)	0.0391	0	326	16.3	18.0	7.02	55.7	35.4	8.25	408	367
2.12	14	0.0578	0.00397	323	14.4	11.3	5.27	73.7	26.2	0	230	208
	16	0.0607	0.00164	279	14.3	13.1	5.65	58.5	28.7	7.09	261	235
	(γ=0)	0.0638	0	249	14.4	18.0	6.85	43.4	34.3	13.2	368	329
2.98	20	0.118	0.0119	211	11.6	9.22	4.47	58.4	20.0	0	151	135
	22	0.125	0.00450	178	11.6	11.1	4.95	43.6	23.6	14.9	176	157
	(γ=0)	0.131	0	158	11.6	18.0	6.59	28.5	32.5	26.8	315	279
4.21	25	0.224	0.0543	136	9.28	7.36	3.71	44.7	15.1	0	97.4	86.7
	27	0.233	0.0179	118	9.21	8.47	3.99	36.3	16.7	20.9	108	95.4
	29	0.240	0.00880	108	9.19	9.80	4.38	30.5	19.1	34.0	123	108
	31	0.249	0.000890	98.1	9.18	14.4	5.51	21.1	27.0	48.4	199	174
	(γ=0)	0.251	0	96.9	9.18	18.0	6.34	18.2	30.8	51.0	273	240

TABLE IV. PARAMETERS ON CONSTANT r'S (Continued)

r	α	t	$10^{-3}m$	p	u	s	c	ω	T	$10^{-3}W$	H	E
6.19	35	0.440	0.110	81.4	7.09	5.60	3.12	32.1	11.1	0	58.1	50.8
	37	0.452	0.0798	73.6	7.01	6.06	3.20	28.2	11.7	22.7	60.6	52.8
	39	0.466	0.0499	66.2	6.95	6.76	3.34	24.2	12.6	46.3	65.4	56.8
	41	0.483	0.0211	59.2	6.89	8.18	3.66	19.8	14.6	71.6	77.7	67.3
	(γ=0)	0.504	0	53.5	6.85	18.0	6.04	10.6	28.9	98.3	235	205
9.17	45	0.862	0.360	45.2	5.21	3.99	2.60	22.8	7.34	0	32.3	27.8
	47	0.890	0.262	39.7	5.11	4.42	2.66	19.4	7.83	40.3	33.5	28.6
	49	0.924	0.168	34.7	5.00	5.02	2.77	16.1	8.56	80.8	35.6	30.2
	51	0.965	0.0818	30.0	4.88	6.02	2.97	12.8	10.0	122	40.8	34.3
	53	0.990	0.0432	27.8	4.82	6.98	3.16	10.9	11.4	143	47.2	39.6
	55	1.02	0.00976	25.8	4.75	9.59	3.77	8.60	15.0	166	70.9	59.9
	(γ=0)	1.03	0	25.1	4.71	18.0	5.72	5.31	26.8	178	202	174
11.4	50	1.26	0.698	31.2	4.28	3.12	2.30	18.3	5.63	0	22.3	18.9
	52	1.30	0.558	27.8	4.19	3.42	2.34	16.0	5.88	39.4	22.7	19.2
	54	1.32	0.468	25.7	4.13	3.64	2.38	14.6	6.09	65.2	23.1	19.4
	56	1.35	0.381	23.7	4.06	3.95	2.43	13.1	6.38	90.7	23.7	19.9
	58	1.38	0.297	21.7	3.99	4.25	2.48	11.8	6.70	116	24.5	20.5
	60	1.42	0.216	19.9	3.92	4.68	2.56	10.4	7.19	141	25.9	21.5
	62	1.46	0.142	18.2	3.83	5.25	2.67	9.02	7.93	166	28.2	23.2
	64	1.50	0.0746	16.5	3.74	6.16	2.86	7.55	9.25	192	32.9	27.0
	66	1.56	0.0177	15.1	3.64	8.49	3.34	5.73	12.5	220	50.1	41.5
	(γ=0)	1.59	0	14.5	3.58	18.0	5.51	3.26	25.5	235	182	157
15.4	61	2.13	1.70	17.8	3.18	2.05	1.92	13.1	3.84	0	12.7	10.7
	63	2.18	1.48	16.1	3.10	2.21	1.94	11.8	3.92	35.4	12.7	10.6
	65	2.23	1.26	14.6	3.02	2.40	1.96	10.6	4.02	69.8	12.7	10.6
	67	2.29	1.05	13.1	2.93	2.61	1.98	9.46	4.13	103	12.8	10.6
	69	2.35	0.854	11.7	2.84	2.87	2.01	8.34	4.27	135	13.0	10.6
	71	2.43	0.667	10.4	2.75	3.18	2.06	7.28	4.49	166	13.4	10.9
	73	2.51	0.492	9.12	2.64	3.58	2.12	6.27	4.81	196	14.0	11.3
	75	2.61	0.331	7.99	2.52	4.11	2.22	5.28	5.27	225	15.2	12.1
	77	2.73	0.188	6.94	2.39	4.86	2.37	4.33	6.08	254	17.4	13.8
	79	2.87	0.0176	5.98	2.23	6.22	2.66	3.30	7.85	282	23.1	18.2
	(γ=0)	3.04	0	5.17	2.04	18.0	5.16	1.38	23.3	314	155	133

TABLE IV. PARAMETERS ON CONSTANT r'S (Continued)

r	α	t	10^{-3}m	p	u	s	c	ω	T	10^{-3}W	H	E
20.7	71	3.69	4.15	9.41	2.24	1.13	1.60	8.86	2.62	0	6.7[illegible]	5.56
	73	3.79	3.62	8.24	2.15	1.26	1.60	7.88	2.64	44.3	6[illegible]	5.40
	75	3.92	3.10	7.15	2.05	1.40	1.61	6.93	2.66	85.8	[illegible].40	5.23
	77	4.06	2.62	6.12	1.95	1.58	1.61	6.02	2.68	124	6.20	5.07
	79	4.22	2.16	5.17	1.83	1.78	1.62	5.17	2.72	159	6.14	4.92
	81	4.41	1.75	4.28	1.70	2.01	1.64	4.37	2.77	191	6.05	4.78
	83	4.63	1.38	3.48	1.55	2.29	1.66	3.66	2.86	219	6.06	4.74
	85	4.87	1.07	2.74	1.37	2.59	1.68	3.00	2.95	242	6.06	4.68
	87	5.57	0.588	1.58	0.977	3.35	1.76	1.97	3.25	280	6.44	4.84
	89	6.48	0.277	1.13	0.816	4.34	1.93	1.46	3.97	308	8.36	6.25
	91	7.27	0.115	0.959	0.779	5.54	2.19	1.17	5.17	328	11.9	8.98
27.2	78	6.17	9.35	5.02	1.56	0.543	1.38	6.02	1.93	0	3.59	2.92
	80	6.42	8.20	4.18	1.45	0.619	1.37	5.24	1.90	50.1	3.33	2.69
	82	6.72	7.12	3.40	1.33	0.712	1.36	4.49	1.86	93.8	3.07	2.46
	84	7.06	6.12	2.68	1.20	0.819	1.34	3.79	1.82	131	2.81	2.22
	86	7.72	4.82	1.72	0.965	1.01	1.32	2.85	1.76	173	2.40	1.85
	88	8.77	3.62	1.02	0.736	1.26	1.31	2.13	1.75	208	2.16	1.64
	90	9.63	2.96	0.801	0.691	1.45	1.33	1.88	1.79	226	2.22	1.67
	91	10.0	2.71	0.748	0.655	1.54	1.34	1.81	1.82	233	2.29	1.71
33.4	84	12.0	26.4	2.21	0.927	0.156	1.21	3.72	1.46	0	1.58	1.25
	86	13.2	22.3	1.39	0.731	0.198	1.16	2.87	1.36	73.0	1.17	0.910
	88	14.9	18.7	0.800	0.546	0.248	1.13	2.23	1.27	118	0.824	0.632
	90	16.0	17.1	0.628	0.486	0.276	1.11	2.04	1.24	133	0.729	0.555
	91	16.4	16.6	0.588	0.474	0.287	1.11	2.00	1.24	138	0.711	0.541
51.6	86	20.6	64.2	1.12	0.571	0.0427	1.12	2.65	1.26	0	0.800	0.618
	88	23.4	57.5	0.642	0.415	0.0578	1.08	2.12	1.17	65.7	0.514	0.391
	90	24.9	54.8	0.503	0.365	0.0639	1.07	1.97	1.15	83.0	0.428	0.325
	91	25.4	53.9	0.471	0.353	0.0657	1.07	1.93	1.14	87.7	0.407	0.309
68.0	87	33.2	147	0.628	0.362	0.0118	1.07	2.12	1.15	0	0.449	0.339
	89	36.2	140	0.430	0.284	0.0143	1.05	1.90	1.11	41.1	0.317	0.237
	91	37.6	137	0.367	0.259	0.0153	1.05	1.82	1.10	53.1	0.274	0.203
110	98	69.4	621	0.267	0.172	0.00135	1.03	1.71	1.07	0	0.190	0.140
	90	70.7	618	0.243	0.160	0.00137	1.03	1.68	1.06	9.77	0.166	0.120
	92	71.7	615	0.227	0.153	0.00139	1.03	1.66	1.06	16.1	0.155	0.112

ACKNOWLEDGEMENT

Donald Taylor of Computing Laboratory is gratefully acknowledged for his coding the problem and running it in the ORDVAC computer.

Ray C Makino
RAY C. MAKINO

Ralph E Shear
RALPH E. SHEAR

REFERENCES

1. Makino, R. C., "An Approximation Method in Blast Calculations," Ballistic Research Laboratories Memo Report No. 1034, Aberdeen Proving Ground, Md., Feb. 1956.

2. Courant, R. and Friedrichs, K. O., "Supersonic Flow and Shock Waves," Interscience Publishers, New York, 1948.

3. Shear, R. E. and Day, B. D., "Tables of Thermodynamic and Shock-Front Parameters for Air," Ballistic Research Laboratories Memorandum Report No. 1206, Aberdeen Proving Ground, Md., May 1959.

4. Goodman, H. J., "Compiled Free-Air Blast Data on Bare Spherical Pentolite," Ballistic Research Laboratories Report No. 1092, Aberdeen Proving Ground, Md., Feb. 1960.

5. Kirkwood, J. G., and Brinkley Jr., S. R., "Theory of the Propagation of Shock Waves from Explosive Sources in Air and Water," NDRC Report No. A-318 (OSRD Report No. 4814), Division 2, National Defense Research Committee of the Office of Scientific Research and Development, Washington D. C., 1945.

6. Clippinger, R. F., and Gerber, N., "Supersonic Flow over Bodies of Revolution (With Special Reference to High Speed Computing)," Ballistic Research Laboratories Report No. 719, Aberdeen Proving Ground, Md., May 1950.

7. Brode, H. L., "A Calculation of the Blast Wave from a Spherical Charge of TNT," U. S. Air Force Project Rand Research Memorandum No. 1965, Rand Corporation, Santa Monica, California, Aug. 1957.

DISTRIBUTION LIST

No. of Copies	Organization
10	Commander Armed Services Technical Information Agency ATTN: TIPCR Arlington Hall Station Arlington 12, Virginia
1	Director IDA/Weapon Systems Evaluation Group Room 1E880, The Pentagon Washington 25, D.C.
1	Director of Defense Research And Engineering (OSD) ATTN: Director/Ordnance Washington 25, D.C.
2	Chief of Ordnance ATTN: ORDTB - Bal Sec Department of the Army Washington 25, D.C.
1	Commanding General Frankford Arsenal ATTN: Library Branch, 0270, Bldg 40 Philadelphia 37, Pennsylvania
3	Commanding Officer Picatinny Arsenal ATTN: Feltman Research and Engineering Laboratories Dover, New Jersey
1	Commanding Officer Diamond Ordnance Fuze Laboratories ATTN: Technical Information Office Branch 012 Washington 25, D.C.
1	Research Analysis Corporation ATTN: Document Control Office 6935 Arlington Road Bethesda, Maryland Washington 14, D.C.
1	Commanding General ATTN: ORDBS-OM-Technical Library RR-10 White Sands Missile Range, New Mexico
1	Army Research Office Arlington Hall Station Arlington, Virginia
3	Chief, Bureau of Naval Weapons ATTN: DIS-33 Department of the Navy Washington 25, D.C.
1	Chief of Naval Operations Department of the Navy Washington 25, D.C.
2	Commander Naval Ordnance Laboratory ATTN: Mr. Wm. Filler Mr. Peter Hanlon White Oak, Silver Spring 19, Maryland
1	Commanding Officer Naval Ordnance Laboratory ATTN: Dr. H.A. Thomas Corona, California
2	Commander U.S. Naval Ordnance Test Station ATTN: Technical Library China Lake, California
1	Commanding Officer Naval Air Development Center Johnsville, Pennsylvania
2	Commander U.S. Naval Weapons Laboratory Dahlgren, Virginia

DISTRIBUTION LIST

No. of Copies	Organization
2	Director Air University Library ATTN: AUL(3T-AUL-60-118) Maxwell Air Force Base, Alabama
2	Commander Air Force Systems Command ATTN: SCRR Andrews Air Force Base Washington 25, D.C.
1	Commander Arnold Engineering Development Center ATTN: AEOI Tullahoma, Tennessee
1	Commander Air Proving Ground Center ATTN: PGAPI Eglin Air Force Base, Florida Of Interest to: PGTWR PGTW
2	Commander Air Force Cambridge Research Laboratory ATTN: CRRDM - Lt. G. Meltz L.G. Hanscom Field Bedford, Massachusetts
1	Commander Air Force Missile Test Center ATTN: J.R. Atkins - MRSS Patrick Air Force Base, Florida
3	Commander Aeronautical Systems Division ATTN: WWAD WWY WWDS Wright-Patterson Air Force Base, Ohio
1	Commander Foreign Technology Center Wright-Patterson Air Force Base, Ohio

No. of Copies	Organization
1	Commander Space Systems Division Air Force Unit Post Office Los Angeles 45, California
1	Director, Project RAND Department of the Air Force 1700 Main Street Santa Monica, California
5	Chief of Staff U.S. Air Force ATTN: AFDRT AFCOA AFORQ (Director/Operational Requirement) Washington 25, D.C.
1	Director of Research & Development U.S. Air Force ATTN: Armament Division, (AFDRD-AR/1) Washington 25, D.C.
1	U.S. Atomic Energy Commission Sandia Corporation Sandia Base Albuquerque, New Mexico
3	University of California Lawrence Radiation Laboratory Technical Information Division ATTN: Clovis G. Craig P.O. Box 808 Livermore, California Of Interest to: Dr. Sidney Fernbach Dr. John Foster Mr. Bruce Crowley
4	U.S. Atomic Energy Commission Los Alamos Scientific Laboratory P.O. Box 1663 Los Alamos, New Mexico

DISTRIBUTION LIST

No. of Copies	Organization
1	Director National Aeronautics and Space Administration 1520 H Street Washington 25, D.C.
1	Director National Aeronautics and Space Administration Langley Research Center ATTN: Mr. Pierce Langley Field, Virginia
1	Aerojet-General Corporation 6352 North Irwindale Road Azusa, California
1	Aerojet-General Corporation Sacramento Plant ATTN: R.G. Weitz P.O. Box 1947 Sacramento 9, California
2	Aircraft Armaments, Inc. ATTN: Mr. R.R. Mills Dr. W. Baker P.O. Box 126 Cockeysville, Maryland
1	Armour Research Foundation Illinois Institute of Technology Center ATTN: F. [illegible]orzel Chicago 16, Illinois
1	Boeing Airplane Company ATTN: Mr. W.A. Pearce Wichita, Kansas
2	Boeing Airplane Company ATTN: Mr. J. Christian - Armament Unit Mr. R.M. Elain - Aero Space Division Seattle 14, Washington
1	Broadview Research Corporation ATTN: Kenneth Kaplan 1811 Trousdale Drive Burlingame, California
1	Chance-Vought Aircraft Company ATTN: Dr. C.C. Wan P.O. Box 5907 Dallas, Texas
1	CONVAIR, A Division of General Dynamics Corporation P.O. Box 1950 San Diego 12, California
1	CONVAIR, A Division of General Dynamics Corporation Fort Worth 1, Texas
1	Cornell Aeronautical Laboratory, Inc. ATTN: Mr. J. Desmond, Librarian Buffalo 5, New York
1	Douglas Aircraft Company Long Beach, California
3	General Electric Company P.O. Box 1088 Schenectady 5, New York
1	General Electric Company Technical Military Planning Operation ATTN: G.M. Shindler Drawer QQ Santa Barbara, California
1	Grumman Aircraft Engineering Corp. ATTN: Armament Group Bethpage, Long Island, New York
1	Hughes Aircraft Company ATTN: Mr. Dana Johnson - Research and Development Laboratories Culver City, California

DISTRIBUTION LIST

No. of Copies	Organization
1	Lockheed Aircraft Corporation ATTN: Mr. R.A. Bailey - Division Engineer Military Operations Research Division Burbank, California
2	The Martin Company ATTN: Mr. S.L. Rosing - Mail No. 356 Middle River, Maryland Mr. Dobray - Mail No. X813 Baltimore 3, Maryland
1	McDonnell Aircraft Corporation ATTN: Armament Group P.O. Box 516 St. Louis 3, Missouri
3	North American Aviation, Inc. ATTN: Mr. D.H. Mason Mr. J. Ward Engineering Technical File 12214 Lakewood Boulevard Downey, California
1	Northrop Aircraft, Inc. 1001 E. Broadway Hawthorne, California
2	Republic Aviation Corporation Farmingdale, Long Island, New York
2	The Rand Corporation ATTN: H.L. Brode F.R. Gilmore 2500 Colorado Avenue Santa Monica, California
1	Space Technology Laboratories, Inc. ATTN: Technical Information Center P.O. Box 95001 Los Angeles 45, California
1	Applied Physics Laboratory The Johns Hopkins University 8621 Georgia Avenue Silver Spring, Maryland
1	Guggenheim Aeronautical Laboratory California Institute of Technology ATTN: H.W. Leipmann Pasadena, California
1	James Forrestal Research Center Department of Aeronautical Engineering ATTN: Mr. Robert McAlevy Princeton, New Jersey
1	The Johns Hopkins University Institute for Cooperative Research 3506 Greenway Baltimore 18, Maryland
2	Massachusetts Institute of Technology ATTN: Dr. James Mar - Bldg 23-111 Dr. Emmett A. Witmer - Room 41-219 Cambridge 39, Massachusetts
1	Massachusetts Institute of Technology Aeroelastic and Structures Research Laboratory Cambridge, Massachusetts
1	Midwest Research Institute ATTN: B.L. Rhodes 425 Volker Boulevard Kansas City 10, Missouri
1	Purdue University Director of Statistical Laboratory ATTN: Dr. Kossach Lafayette, Indiana
1	Stanford Research Institute Menlo Park, California
1	Stevens Institute of Technology Davidson Laboratory ATTN: Mr. L.H. Weeks Castle Point Station Hoboken, New Jersey

DISTRIBUTION LIST

No. of Copies	Organization
1	University of Utah Institute of Rate Processes ATTN: M.A. Cook Salt Lake City, Utah
1	University of Michigan Department of Engineering ATTN: Dr. O. Laporte Ann Arbor, Michigan
1	Professor W. Bleakney Palmer Physical Laboratory Princeton University Princeton, New Jersey
1	Dr. S.R. Brinkley Combustion & Explosives Research, Inc. Alcoa Building Pittsburgh 19, Pennsylvania
5	Mr. Benjamin Day 164 Cornell Quarters Ithaca, New York
1	Professor K.O. Friedrichs New York University Applied Mathematics Panel New York, New York

No. of Copies	Organization
1	Professor J.P. Hirschfelder University of Wisconsin Naval Research Laboratory Madison, Wisconsin
1	Dr. J.S. Rinehart University of Colorado School of Mines Golden, Colorado
10	Commander British Army Staff British Defence Staff (W) ATTN: Reports Officer 3100 Massachusetts Avenue, N.W. Washington 8, D.C. Of Interest to: Mr. G. Simm R.A.E.
4	Defence Research Member Canadian Joint Staff 2450 Massachusetts Avenue, N.W. Washington 8, D.C.

AD ______ Accession No. ______

UNCLASSIFIED

Ballistic Research Laboratories, APG
UNSTEADY SPHERICAL FLOW BEHIND A KNOWN SHOCK LINE
Ray C. Makino, Ralph E. Shear

Shock Waves - Mathematical Analysis
Blast Effects - Measurements

BRL Report No. 1154 November 1961

DA Project No. 503-04-002, OMSC No. 5010.11.815

The hydrodynamical equations of unsteady spherical flow are converted into characteristic form and solved numerically by a difference method. The "initial-value" curve is a least square fit to some compiled data on spherical Pentolite, of such form as to approach Kirkwood-Brinkley's theoretical asymptotic shock-front decay curve. Results are tabulated on positive sound paths, mass particle paths, and lines of constant distance.

AD ______ Accession No. ______

UNCLASSIFIED

Ballistic Research Laboratories, APG
UNSTEADY SPHERICAL FLOW BEHIND A KNOWN SHOCK LINE
Ray C. Makino, Ralph E. Shear

Shock Waves - Mathematical Analysis
Blast Effects - Measurements

BRL Report No. 1154 November 1961

DA Project No. 503-04-002, OMSC No. 5010.11.815

The hydrodynamical equations of unsteady spherical flow are converted into characteristic form and solved numerically by a difference method. The "initial-value" curve is a least square fit to some compiled data on spherical Pentolite, of such form as to approach Kirkwood-Brinkley's theoretical asymptotic shock-front decay curve. Results are tabulated on positive sound paths, mass particle paths, and lines of constant distance.

AD ______ Accession No. ______

UNCLASSIFIED

Ballistic Research Laboratories, APG
UNSTEADY SPHERICAL FLOW BEHIND A KNOWN SHOCK LINE
Ray C. Makino, Ralph E. Shear

Shock Waves - Mathematical Analysis
Blast Effects - Measurements

BRL Report No. 1154 November 1961

DA Project No. 503-04-002, OMSC No. 5010.11.815

The hydrodynamical equations of unsteady spherical flow are converted into characteristic form and solved numerically by a difference method. The "initial-value" curve is a least square fit to some compiled data on spherical Pentolite, of such form as to approach Kirkwood-Brinkley's theoretical asymptotic shock-front decay curve. Results are tabulated on positive sound paths, mass particle paths, and lines of constant distance.

AD ______ Accession No. ______

UNCLASSIFIED

Ballistic Research Laboratories, APG
UNSTEADY SPHERICAL FLOW BEHIND A KNOWN SHOCK LINE
Ray C. Makino, Ralph E. Shear

Shock Waves - Mathematical Analysis
Blast Effects - Measurements

BRL Report No. 1154 November 1961

DA Project No. 503-04-002, OMSC No. 5010.11.815

The hydrodynamical equations of unsteady spherical flow are converted into characteristic form and solved numerically by a difference method. The "initial-value" curve is a least square fit to some compiled data on spherical Pentolite, of such form as to approach Kirkwood-Brinkley's theoretical asymptotic shock-front decay curve. Results are tabulated on positive sound paths, mass particle paths, and lines of constant distance.